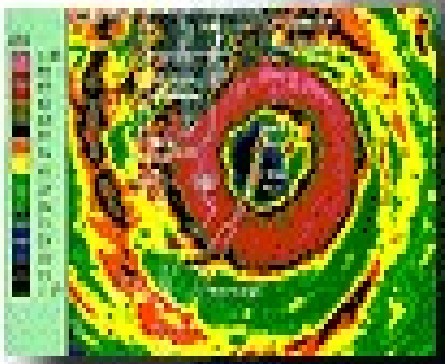
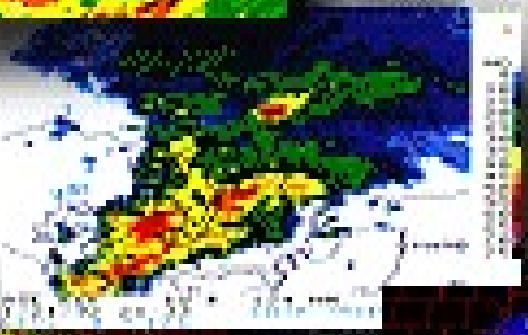
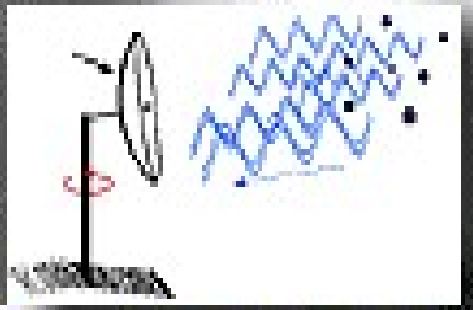
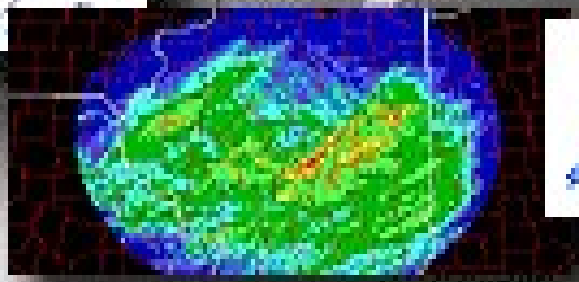
Radar Meteorology

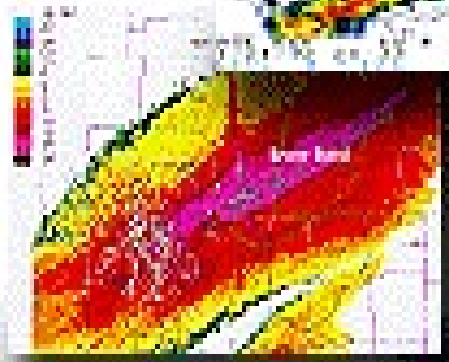
Online Remote Sensing Guide

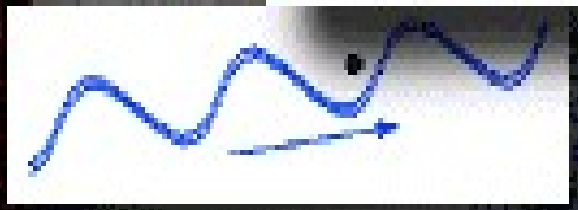








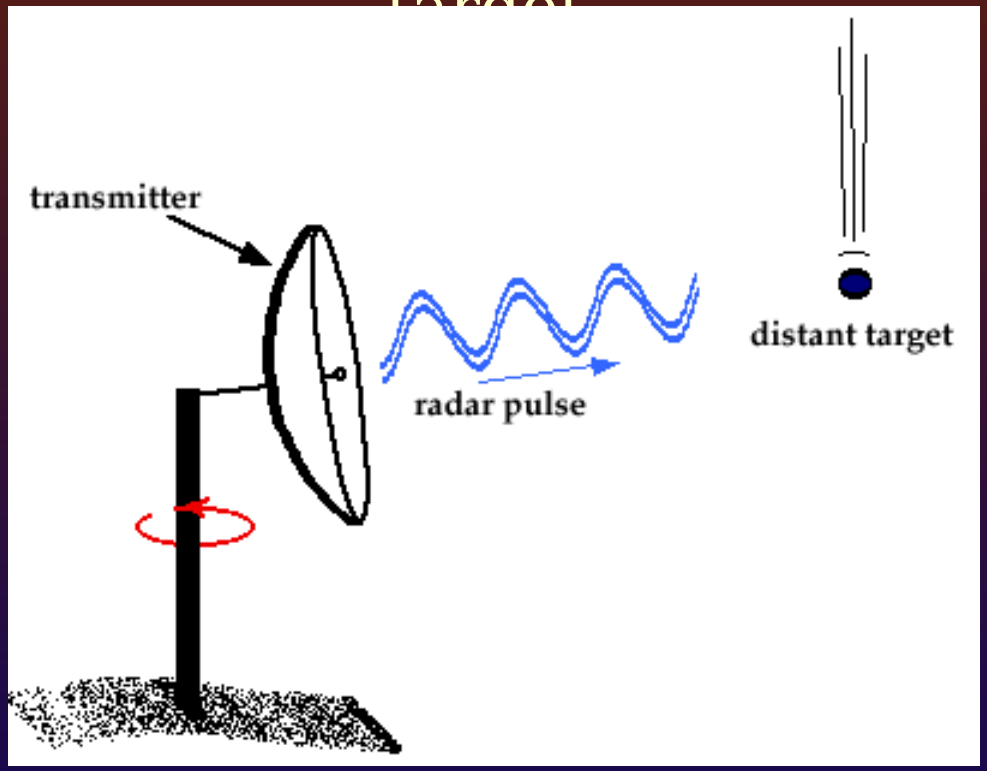




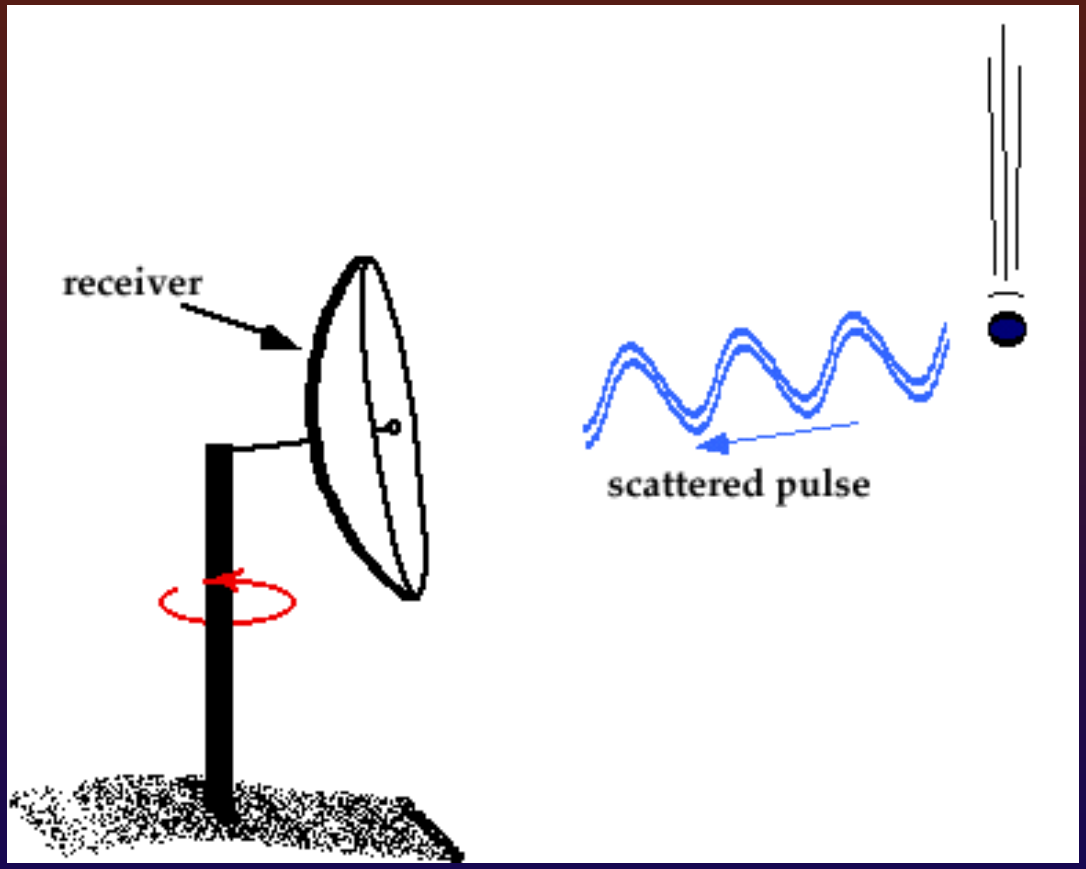


Sending and Receiving Signals

detecting a target



The radar creates an electromagnetic energy pulse which is focused by an antenna and transmitted through the atmosphere. Objects in the path of this electromagnetic pulse, called targets, scatter the electromagnetic energy.

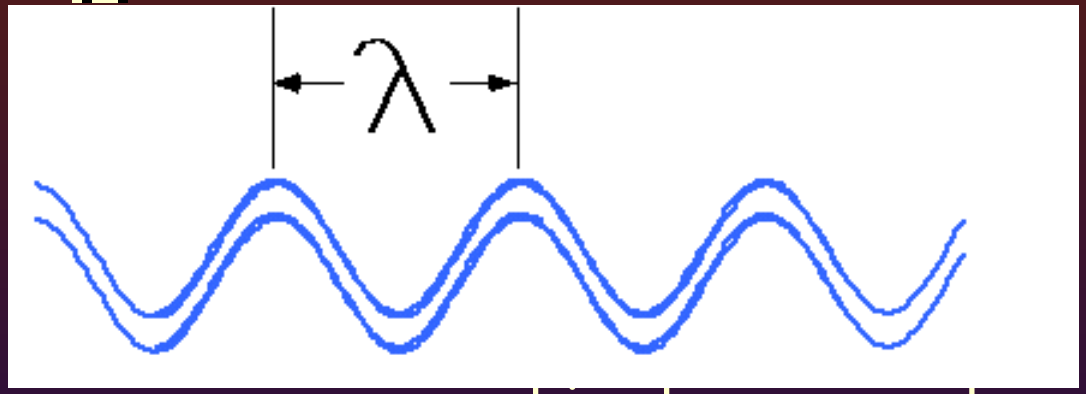


The receiving antenna (which is normally also the transmitting antenna) gathers this back-scattered radiation and feeds it to a device called a receiver.

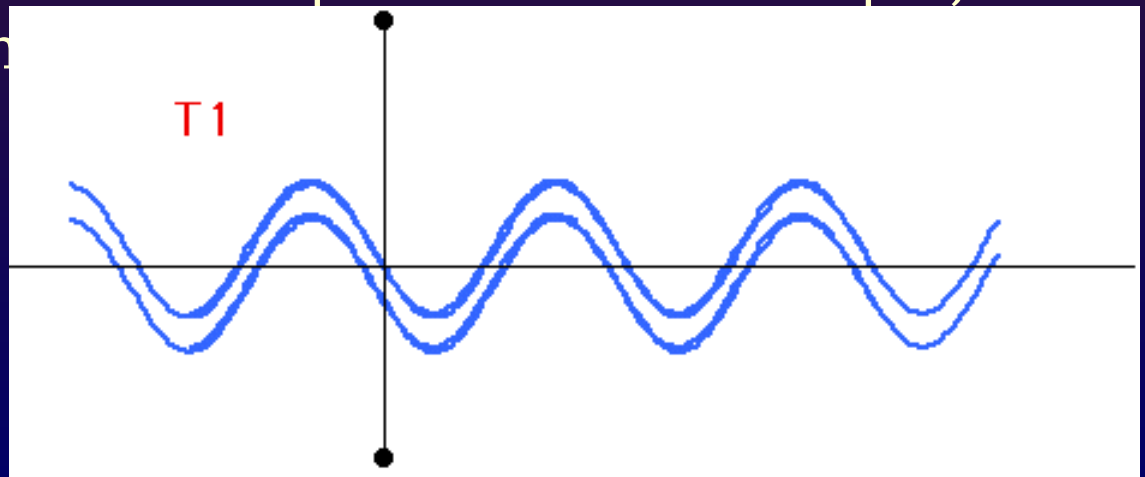
Wave Properties

wavelengths and phase shifts

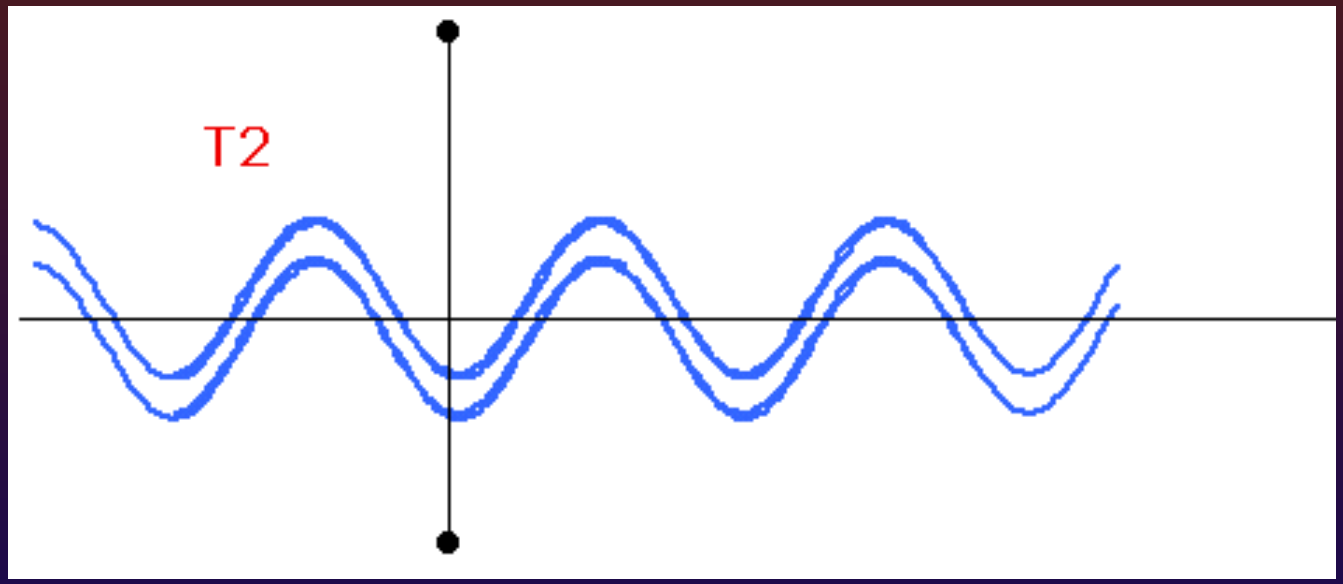
The wavelength (λ) of a wave is the distance from one crest to the



The phase of a wave, measured in degrees, where 360 degrees is one wavelength, indicates the current position of the wave relative to a reference position. For example, if at time T1 the position of th



while at time T2, the position of the wave was:

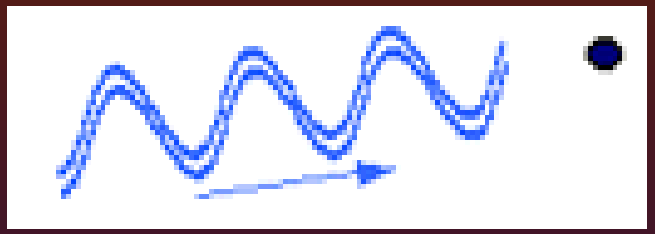


then the wavelength did not change from T1 to T2, but the wave's position relative to the vertical line changed 1/4 wavelength, or 90 degrees. This change is called a

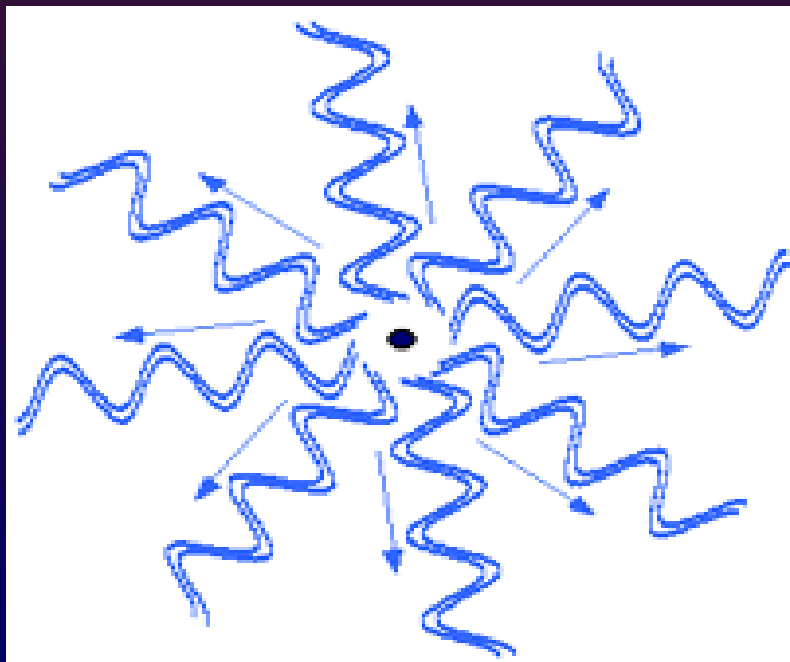
Scattering of a Radar Pulse

by a target back to the receiver

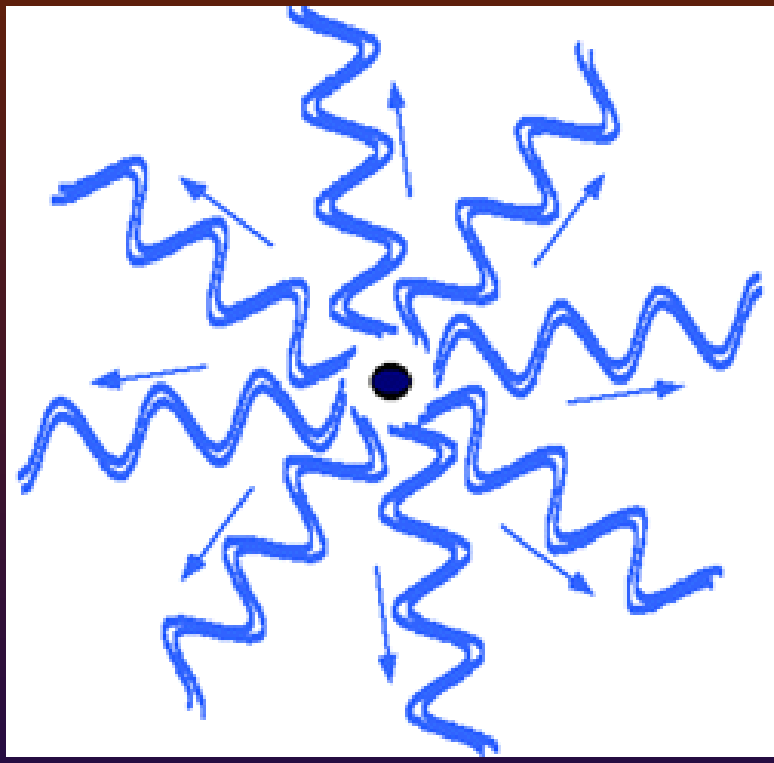
When a pulse encounters a target...



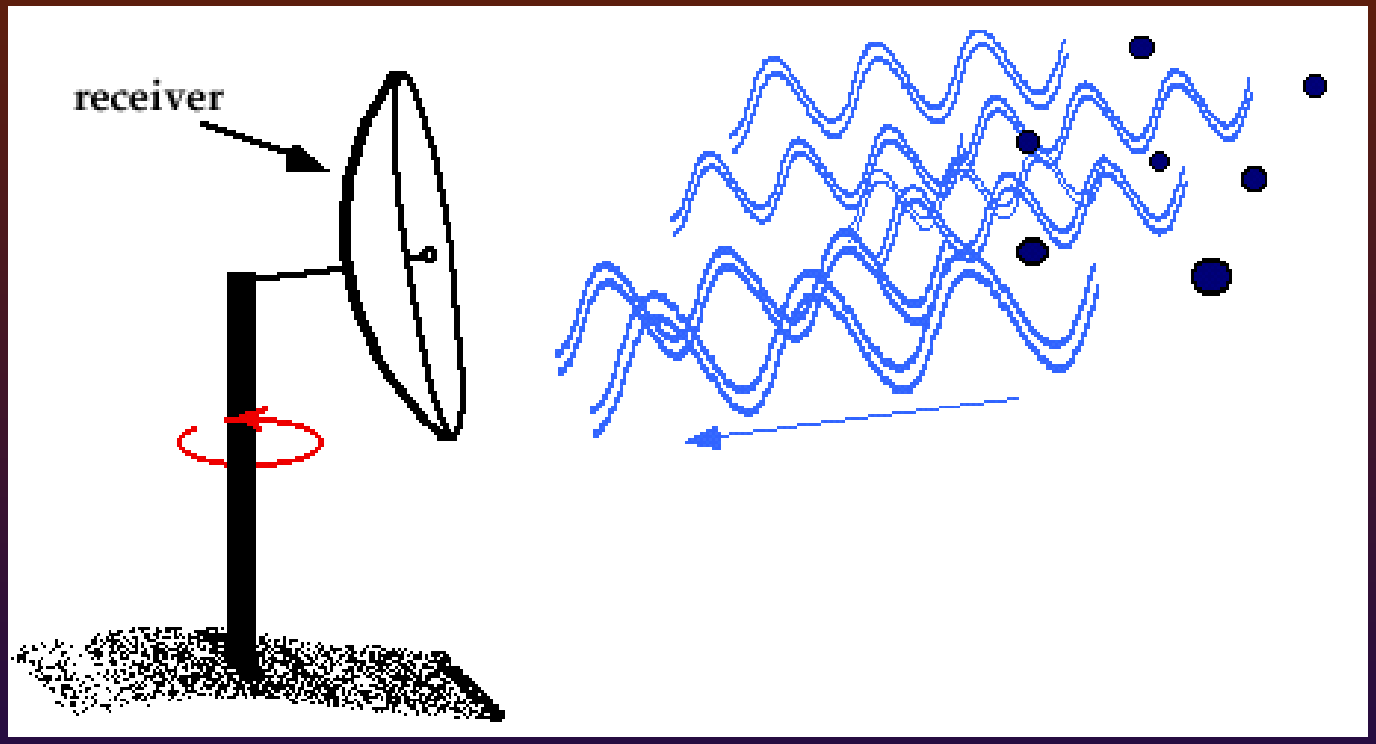
it is scattered in all directions. Of interest is the signal component received back at the radar. This signal is typically much weaker than the original sent from the transmitter and is called the



The larger the target, the stronger the scattered signal.



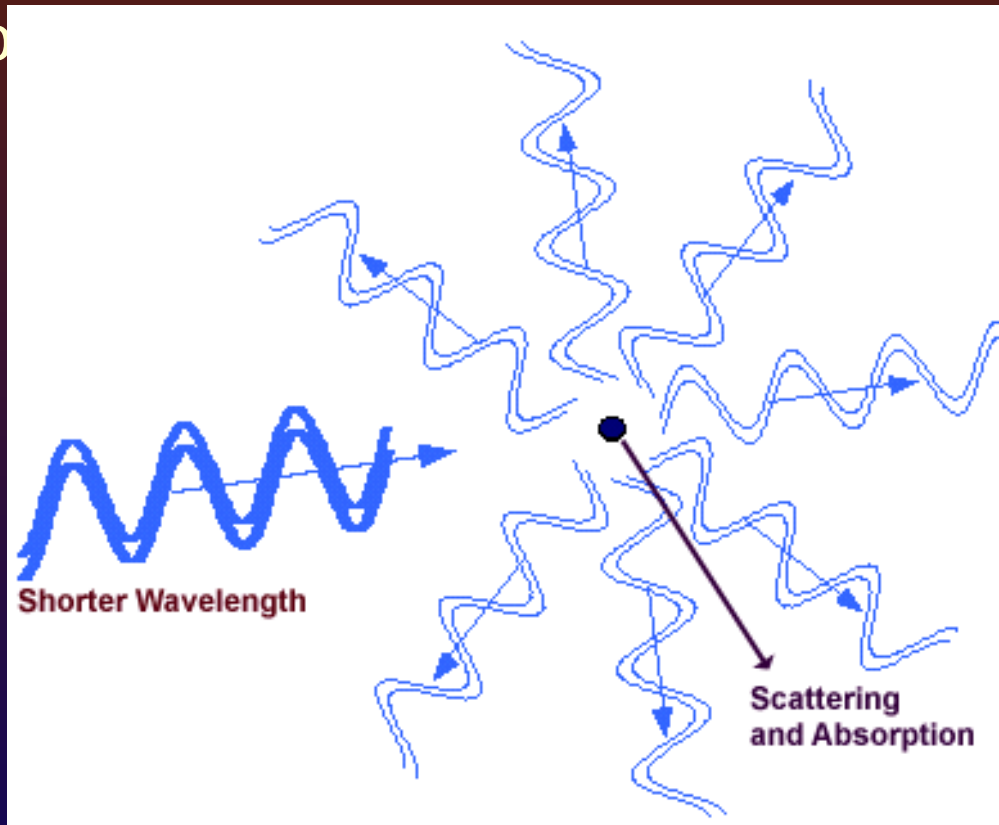
The more targets there are to scatter the pulse, the stronger the return will be because the return signals from each target combine to produce a stronger signal. This means that many large raindrops will produce a stronger return than a few small raindrops. The quantity that a radar measures is the returned power which, with knowledge of other radar characteristics, is converted to a quantity



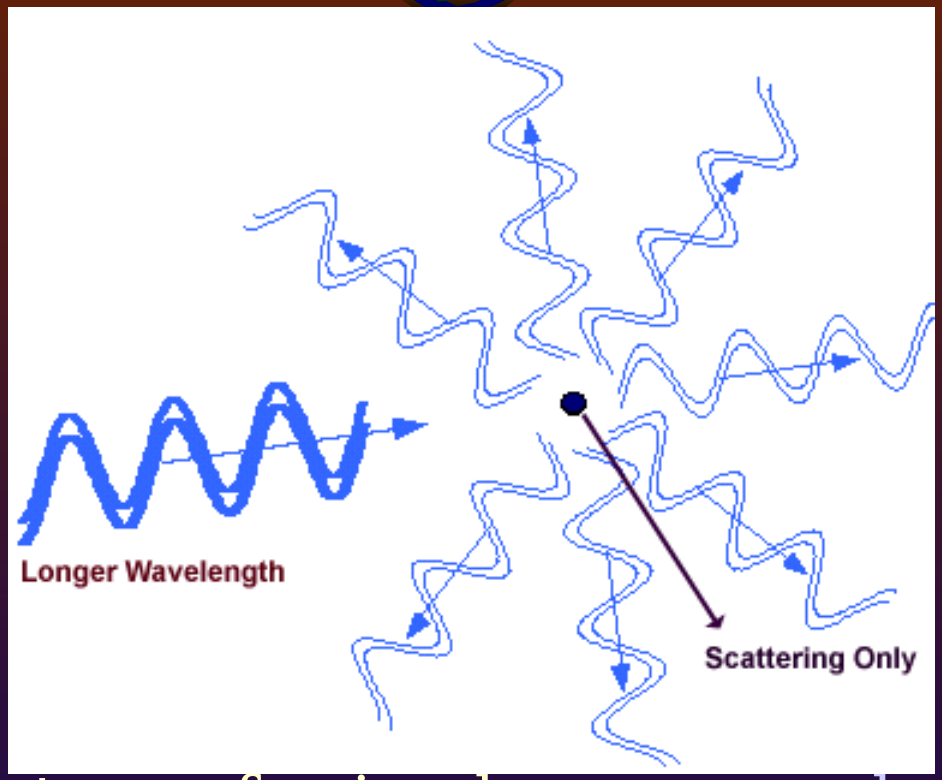
The magnitude of the reflectivity is related to the number and size of the drops encountered by the electromagnetic pulse. For this reason, high reflectivity generally implies heavy precipitation while low reflectivity implies lighter precipitation. Plots of the radar reflectivity, typically using colors to depict its magnitude, show both the

Effects of Wavelength on the ability to detect an ob

The factors which govern the choice of a wavelength to be used in a particular radar include its sensitivity, which is its ability to detect weak targets at long range, the radar's ability to resolve small features, the types of targets to be studied, and the effects of the intervening atmosphere on the transmitted energy. Other factors also must be considered such as the radar's size, weight and cost. Most weather radars have wavelengths that range between 0.8 centimeters (3 in) and 10.0 cm. Generally short wavelength systems are smaller, lighter and less expensive equipment.



Short wavelength radars are more effective in detecting small particles such as cloud droplets and drizzle drops. However, the short wavelength electromagnetic energy is also partially absorbed by these same particles (a process called attenuation). This makes it difficult to accurately measure the intensity of back-scattered energy for more distant targets that lie beyond

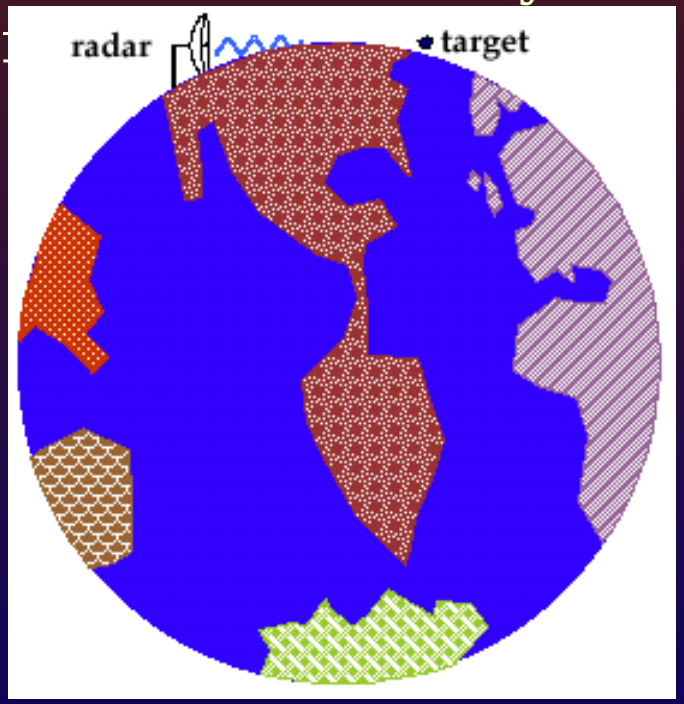


The main advantage of using longer wavelengths is that absorption by the intervening particles is drastically reduced. This means that a distant thunderstorm behind a closer thunderstorm will appear on the radar screen with its proper intensity. Since detecting severe weather is one of the most important missions of operational radars, such as the National Weather Service's

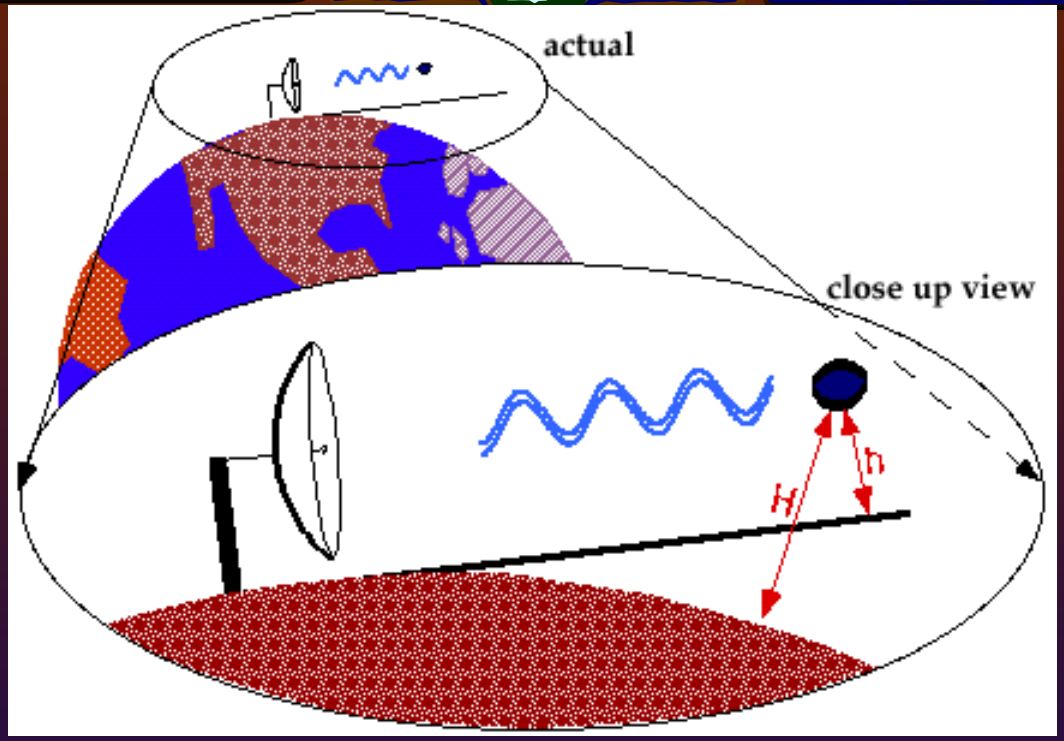
Effects of the Earth's Curvature and Atmospheric Refraction

on estimating a target's position

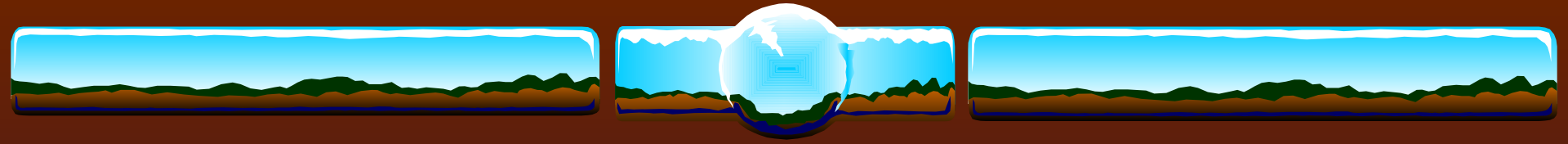
One must account for the curvature of the earth when determining the altitude of a target. Distant targets, which are close to the ground, cannot be seen by a radar because they will be below the hor



The height of a distant target that is above the horizon will be underestimated if the curvature of the earth is not taken into account. For example, the height of the target on the figure below



A second effect, called refraction, also affects the path the electromagnetic energy will take as it propagates through the atmosphere. Normally, because the atmosphere's density decreases rapidly with height, the radar beam will be deflected downward, much like light passing through a glass prism. In extreme cases, where temperature increases with height and dry air overlays warm air, (a condition often found along coastlines), the beam can bend down dramatically and even strike the ground. Meteorologists call this effect "anamolous propagation". Both the curvature of the earth

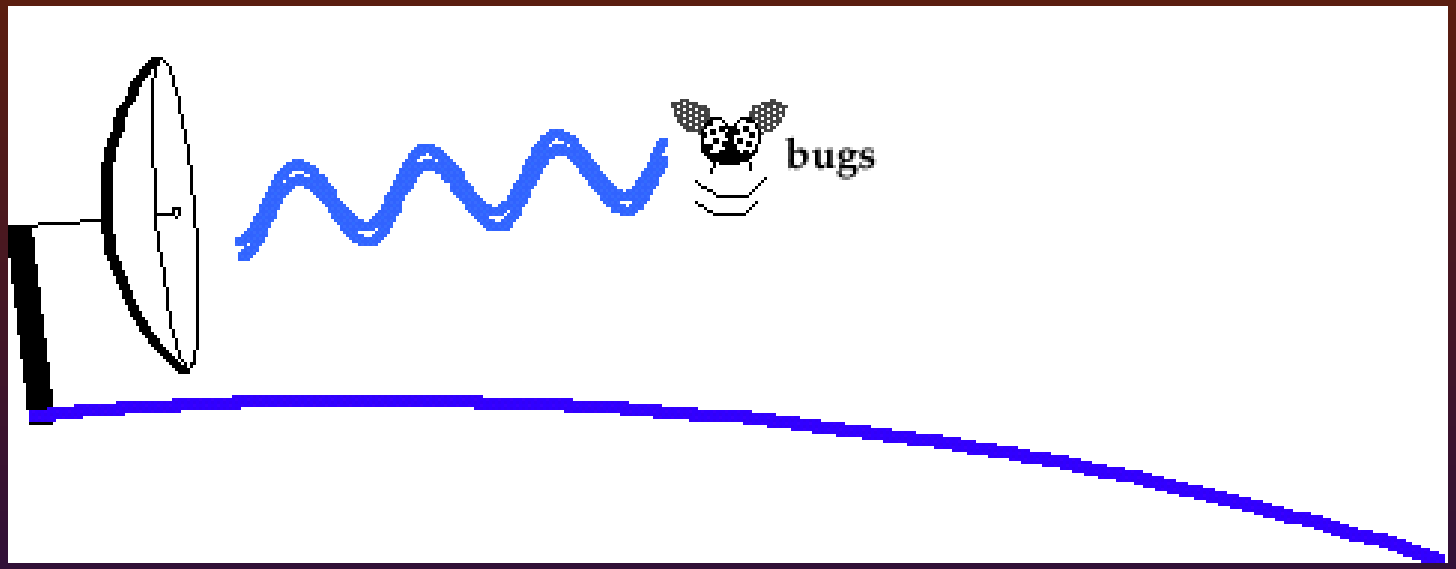


Clear Air Returns

insects and
temperature
turbulence

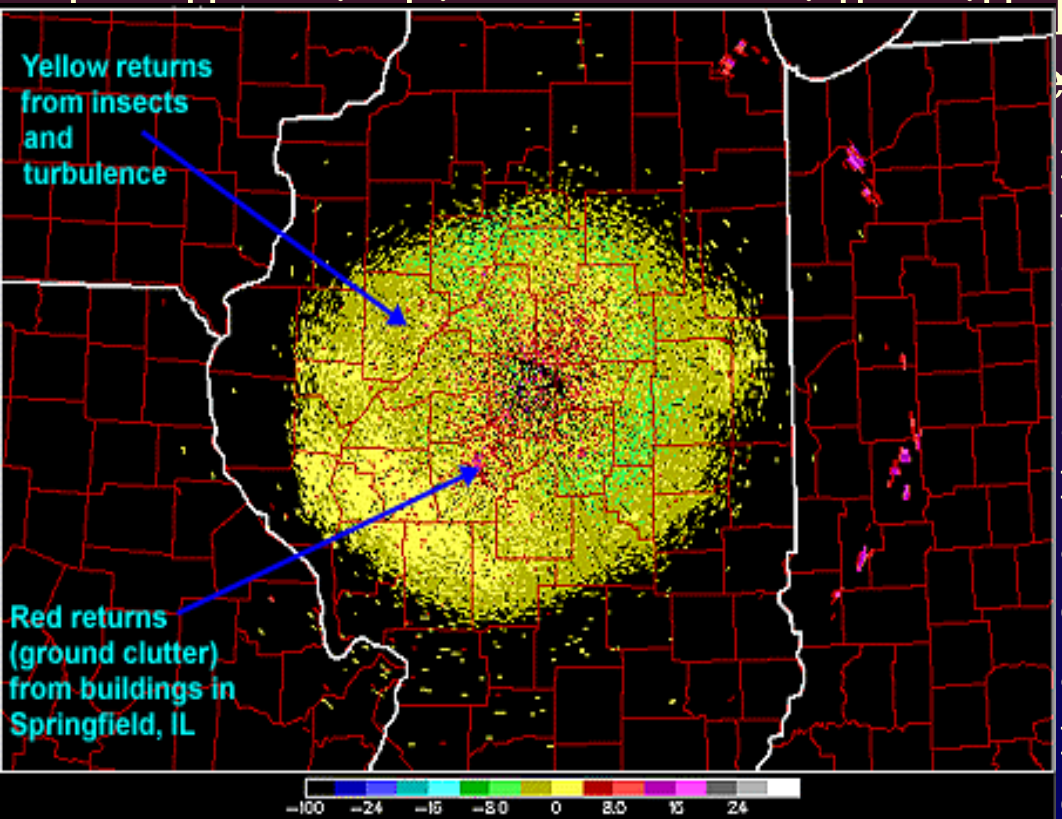
When a radar transmits energy, part of it may be intercepted by targets on the ground, such as buildings, trees, cars, or other objects. The return signal from these objects is called "ground clutter". Ground clutter interferes with the detection of meteorological targets, such as raindrops, because ground targets are large and typically produce high reflectivity. Ground clutter can result even if the main radar beam is above ground targets because part of the energy radiated from the antenna is emitted off the beam axis in what are known as "sidelobes". Back-scattered energy from the sidelobes is interpreted by the radar processor to come from the main lobe, so ground targets hit by one of the sidelobes appear to a radar user in the same relative position in the main lobe.

Ground clutter is usually the worst within about 20 kilometers of the radar site where the beam is still close to the earth's surface. Farther from the site, the beam is higher due to both its elevation angle and curvature of the earth away from the radar site. Ground clutter is easily identified with a Doppler radar because the radial velocity measured by the Doppler radar will approximately be zero since none of the ground targets are moving with respect to the radar. The radial velocity is not exactly zero because moving targets

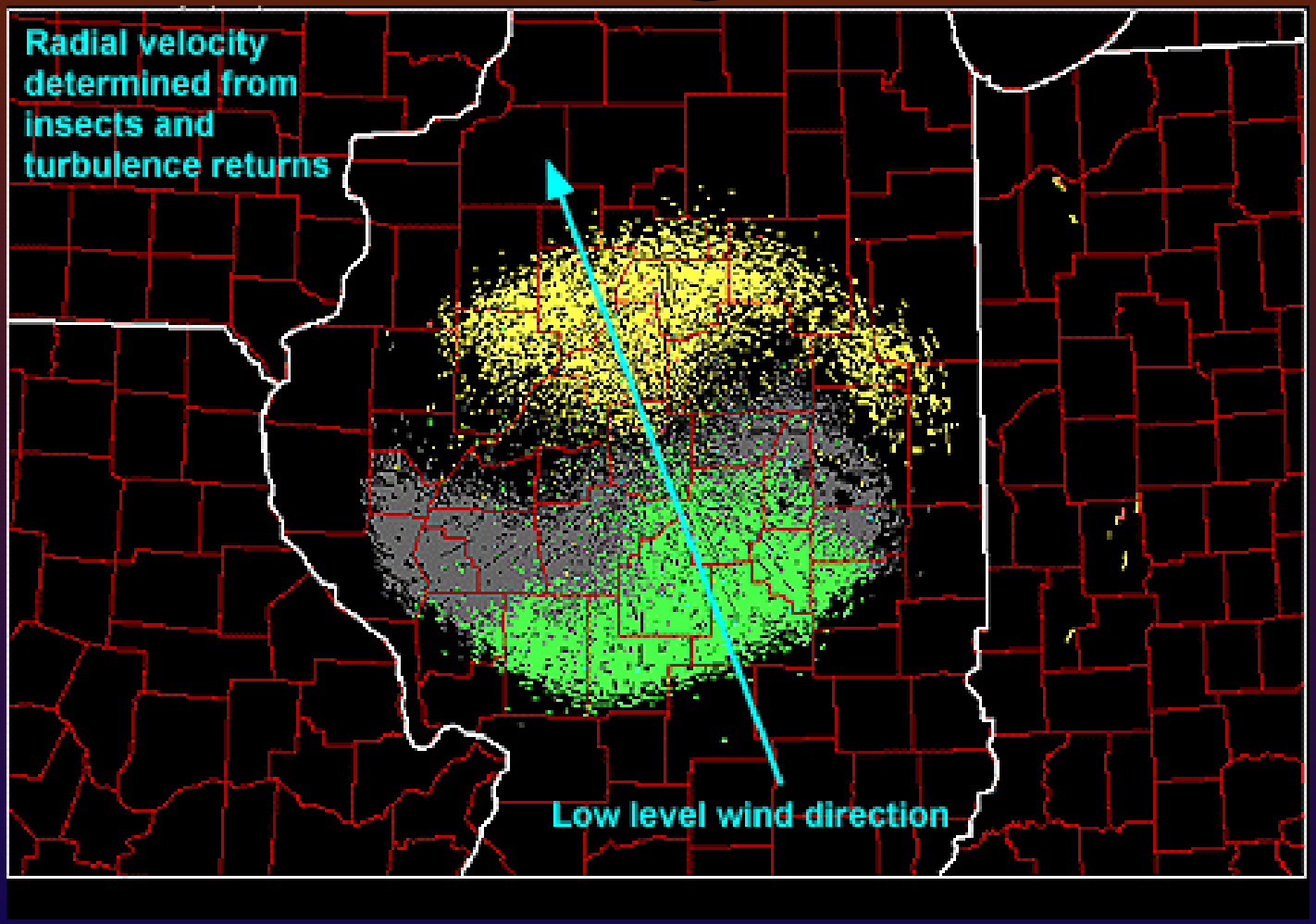


Insects present large targets to radar and they are always present during the warmer seasons. This actually is beneficial to meteorologists. Doppler radars require targets to determine the motion of the air. Outside of regions where precipitation is falling, there would be no targets if there were no insects. Airborne insects turn out to be very good tracers of air motion since, on average, they blow along with the wind. The returns from insects allow meteorologists to see air motions outside

Turbulence provides another way in which electromagnetic energy from a radar can be back-scattered. Turbulence is associated with variations in density in the atmosphere. When variations in density occur on a scale of half the wavelength of the radar, energy is scattered through a process called diffraction. Radar echoes in a clear atmosphere will be more common on days when the lower atmosphere is unstable, as when there are thermals present, or [illegible] height just above the ground,



The picture above shows the radar reflectivity measured by the National Weather Service Doppler radar at Lincoln, IL (ILX) on a beautiful clear day. Radar returns are due to insects, turbulent motions, and ground targets. These echoes, which extend out to about 100 kilometers from the radar, allow the radar operator to see the air motion.

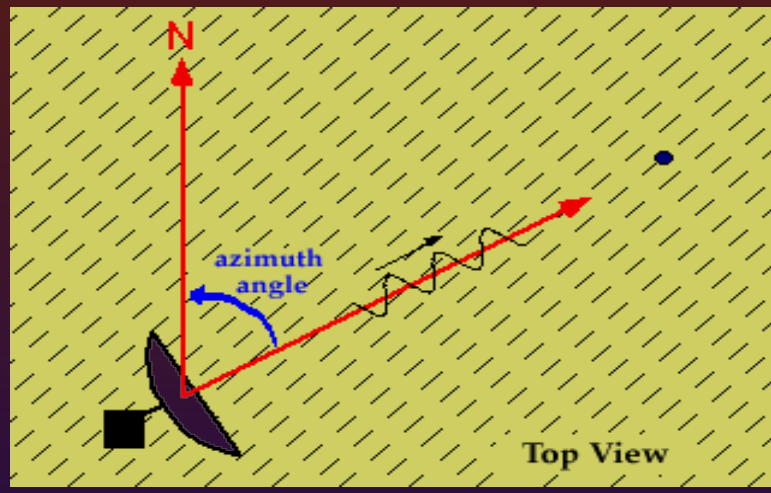


This second picture shows the corresponding radial velocity field. The distribution of inbound (green) and outbound (yellow) velocities indicate that the low

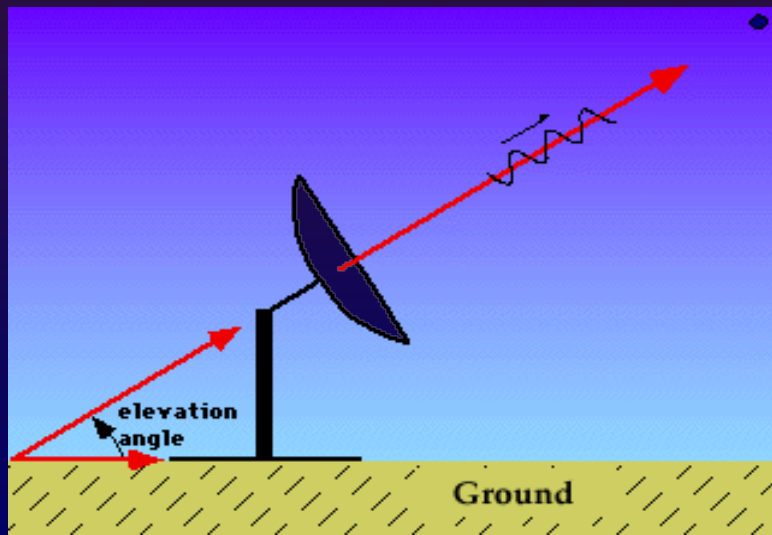
Locating a target

angles and distances used

The radar needs 3 pieces of information to determine the location of a target

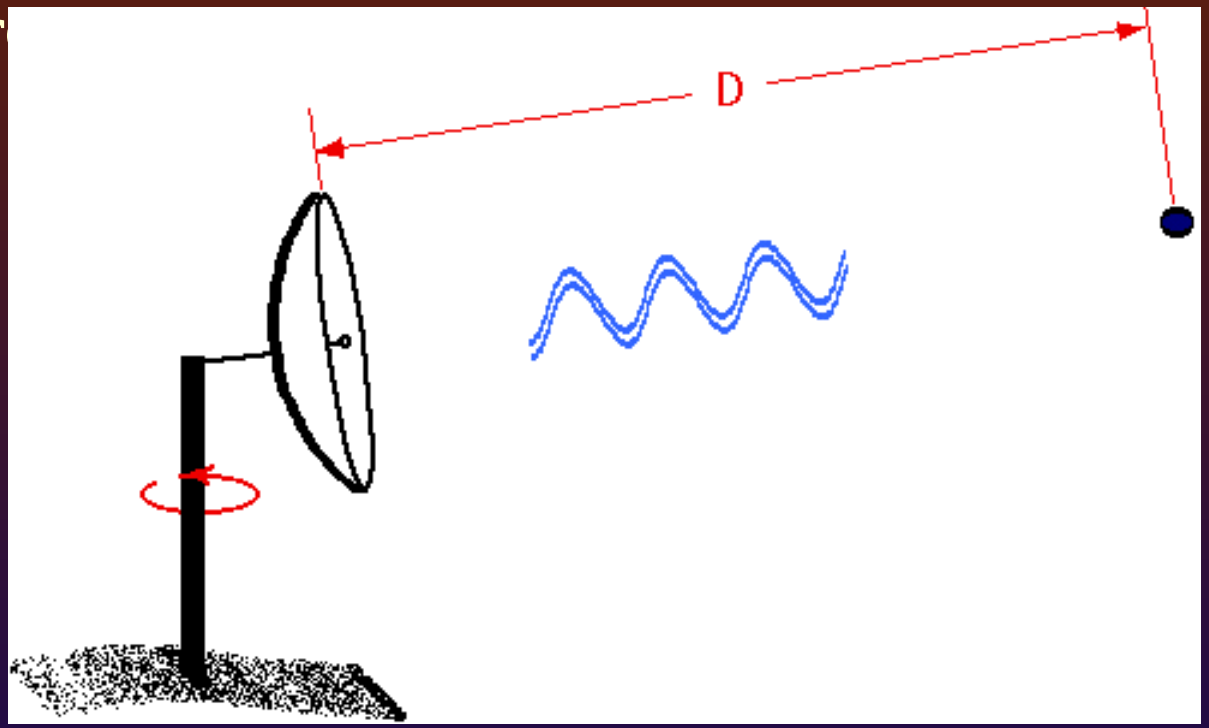


The first piece of information is the angle of the radar beam with respect to north; called the "azimuth angle".



The second is the angle of the beam with respect to the ground; called the "elevation angle"

The third piece of information needed is the distance (D) from radar to tar

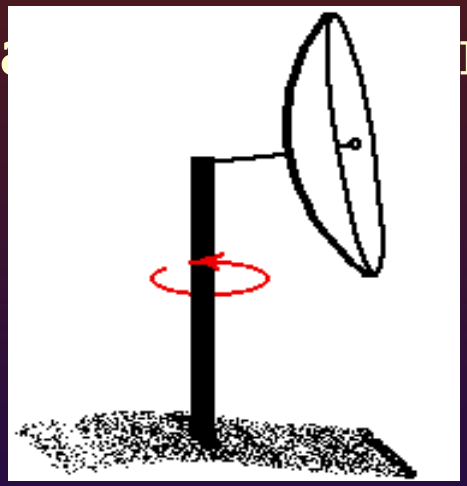


Distance is determined by measuring the time it takes for the pulse to make a round trip from the radar to the target and back using the relation *distance = (time) * (velocity)*. The velocity is the speed of light, the speed at which the pulse travels (c). Since the pulse has to travel to the target and back, the total distance is 2D. If **t** is the time it takes, then 2D = ct or D = ct/2. Using the calculated distance,

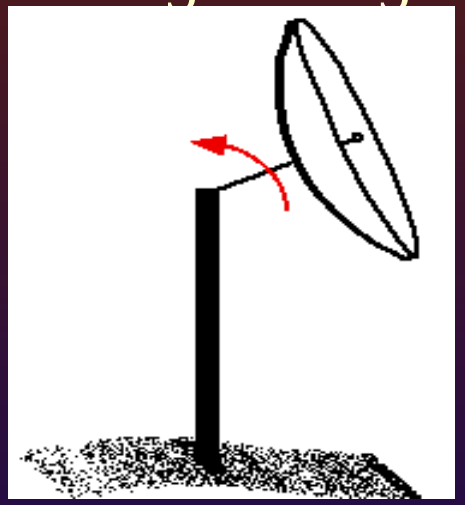
Scanning Modes

PPI and RHI

The two main types of scans used in meteorology are the Plan Position Indicator (PPI) and the Range Height Indicator (RHI) scans.



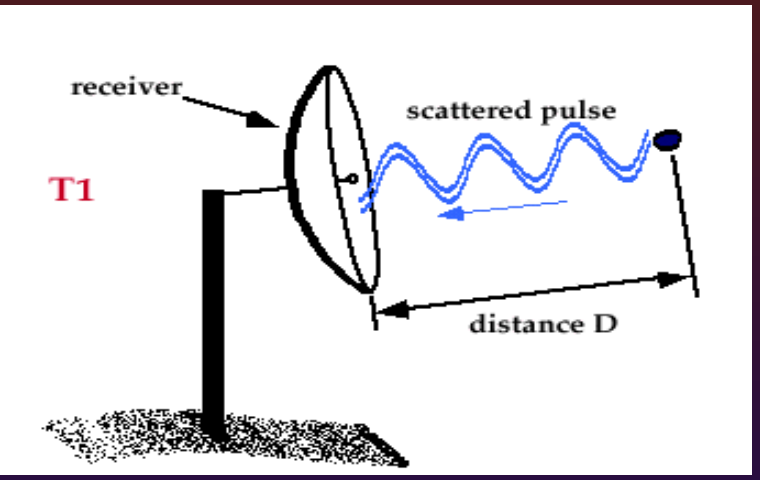
Plan Position Indicator (PPI): When scanning in PPI mode, the radar holds its elevation angle constant but varies its azimuth angle. The returns can then be mapped on a horizontal plane. If the radar rotates through 360 degrees, the scan is called a "surveillance scan". If the radar

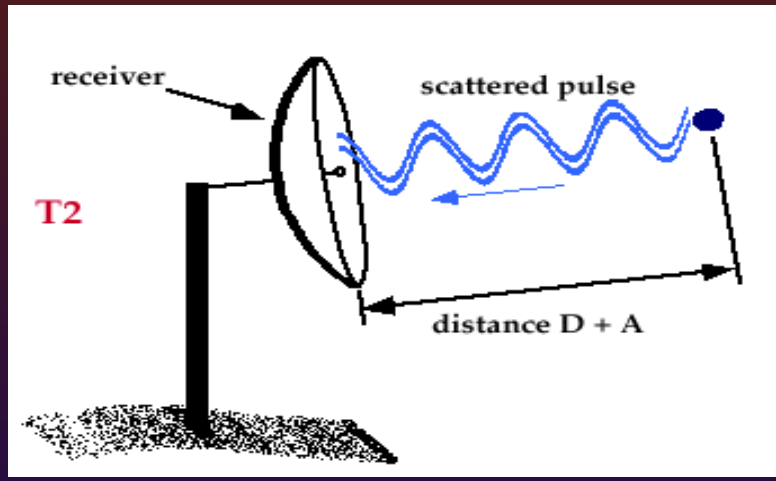


Range Height Indicator (RHI): When scanning in RHI mode, the radar holds its azimuth angle constant but varies its elevation angle. The returns can then be mapped on a vertical plane. The elevation angle normally is rotated from near the horizon to near the zenith (the

Radial velocity measured by Doppler radars

Doppler radars can measure the component of the velocity of targets toward or away from the radar. This component is called the "radial velocity".





For example, at time T1 a pulse is sent towards a target and it returns a target distance "D".

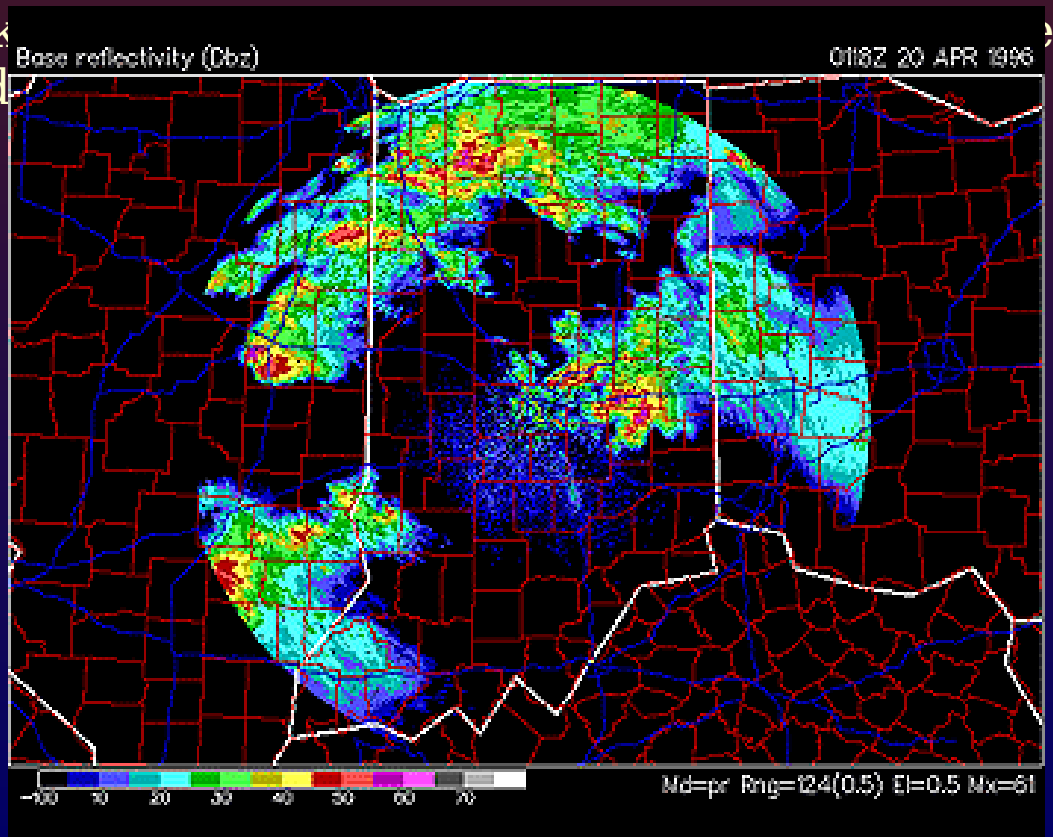
2) At time T2, another pulse is sent towards the same target and returns a target distance "D+A"

The distance to target has changed from times T1 to T2, resulting in a phase shift between the two return signals, which Doppler radars are capable of measuring. By knowing the phase shift, the wavelength and the time interval from T1 to T2, the velocity the target has moved toward or away from the radar can be computed. If the target is moving sideways so

WSR-88D Radar Imagery

detecting precipitation

The word radar is an acronym from "Radio Detection and Ranging". Radar images are useful for locating precipitation. As a Magnetic Resonance Imaging (MRI) scan examines the inside of a human body, a radar examines the inside of a cloud. A radar sends a pulse of energy into the atmosphere and if any precipitation is intercepted by the energy, part of the energy is scattered back[illegible]ed "radar echoes", are assembled[illegible]



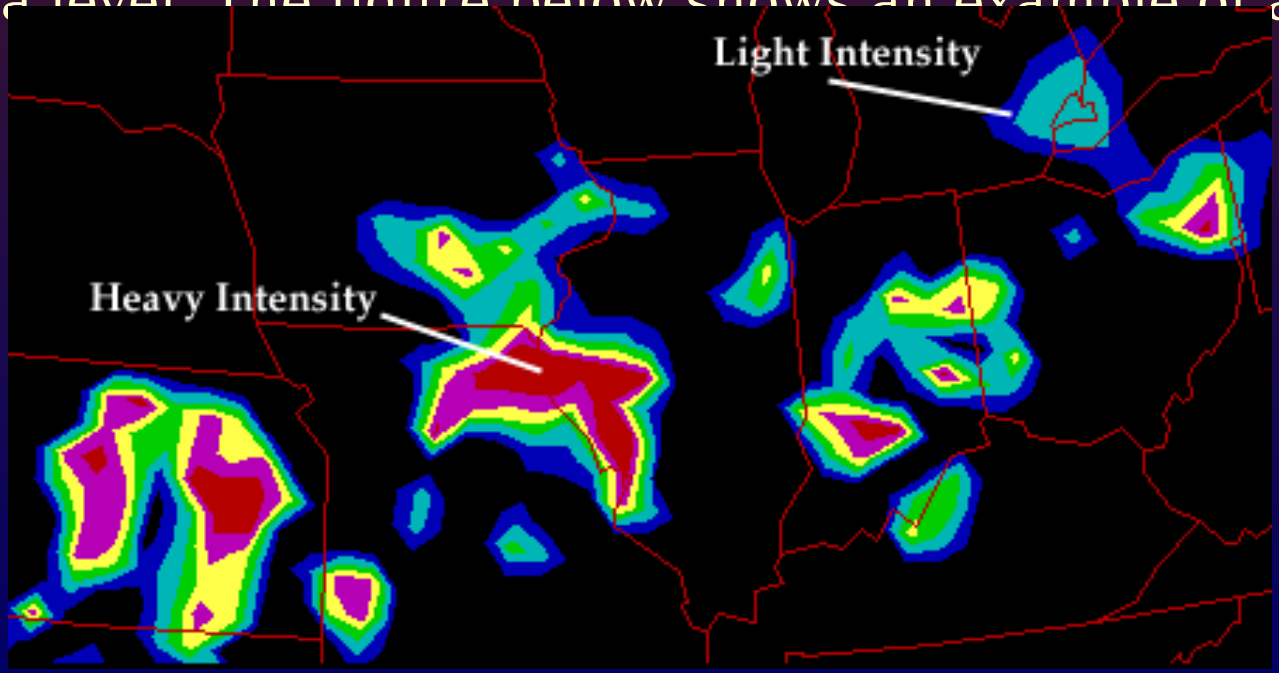
The location of the colored radar echoes indicate where precipitation is falling and the various colors indicate the intensity of the precipitation through the color code in the lower left corner of the image. The example radar image above shows several strong thunderstorms moving through Illinois and Indiana on April 20, 1996. Regions of light and dark blue indicate regions of lighter precipitation while areas of red and pink indicate strong, to occasionally severe thunderstorms.

Normally, it is difficult to distinguish precipitation type on the basis of the radar reflectivity alone. Snow and light drizzle both produce radar reflectivity with about the same value. Melting snow and moderate rain also have similar values. Very high reflectivities (the grays on

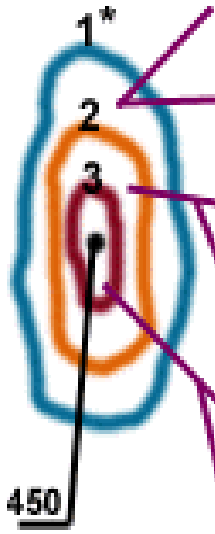
MDR Images

manually digitized radar

Manually Digitized Radar (MDR) images are low resolution radar depictions available from the National Weather Service. These images show the echo intensity in six categories. There also a number of symbols indicating precipitation type, cell movement, line movement, and echo coverage. Severe thunderstorm and tornado watches, line echo wave patterns, and hook echoes are also indicated. The height of cloud tops is also indicated in hundreds of feet above sea level. The figure below shows an example of an MDR image.



The table below summarizes the features of MDR images.



VIP** Level	Echo Intensity	Precipitation Intensity	Rainfall Rate (in/hr) Stratiform	Rainfall Rate (in/hr) Convective	Reflectivity in (dBZ)
1	Weak	Light	Less Than 0.1	Less Than 0.2	Min. Signal - 30
2	Moderate	Moderate	0.1 - 0.5	0.2 - 1.1	31 - 40
3	Strong	Heavy	0.5 - 1.0	1.1 - 2.2	41 - 45
4	Very Strong	Very Heavy	1.0 - 2.0	2.2 - 4.5	46 - 50
5	Intense	Intense	2.0 - 5.0	4.5 - 7.1	51 - 57
6	Extreme	Extreme	More Than 5.0	More Than 7.1	> 57

Highest precipitation top in area in hundreds of feet MSL (45,000 feet MSL).

Symbol	Meaning
R	Rain
RW	Rain Shower
HAIL	Hail
S	Snow
IP	Ice Pellets
SW	Snow Shower
L	Drizzle
T	Thunderstorm
ZR, ZL	Freezing Precipitation
NE	No Echoes Observed
NA	Observations Unavailable
OM	Out For Maintenance
STC	STC ON - all precipitation may not be seen
ROBEPS	Radar Operating Below Performance Standards
RHINO	Range Height Indicator Not Operating

These symbols represent various types of precipitation and

Symbol	Meaning
+	Intensity Increasing Or New Echo
-	Intensity Decreasing
NO SYMBOL	No Change In Intensity
35 	Cell Movement to NE At 35 Knots
	Line Or Area Movement To East At 20 Knots
LM	Little Movement
MA	Echoes Mostly Aloft
PA	Echoes Partly Aloft

These symbols indicate speed and direction of movement, plus

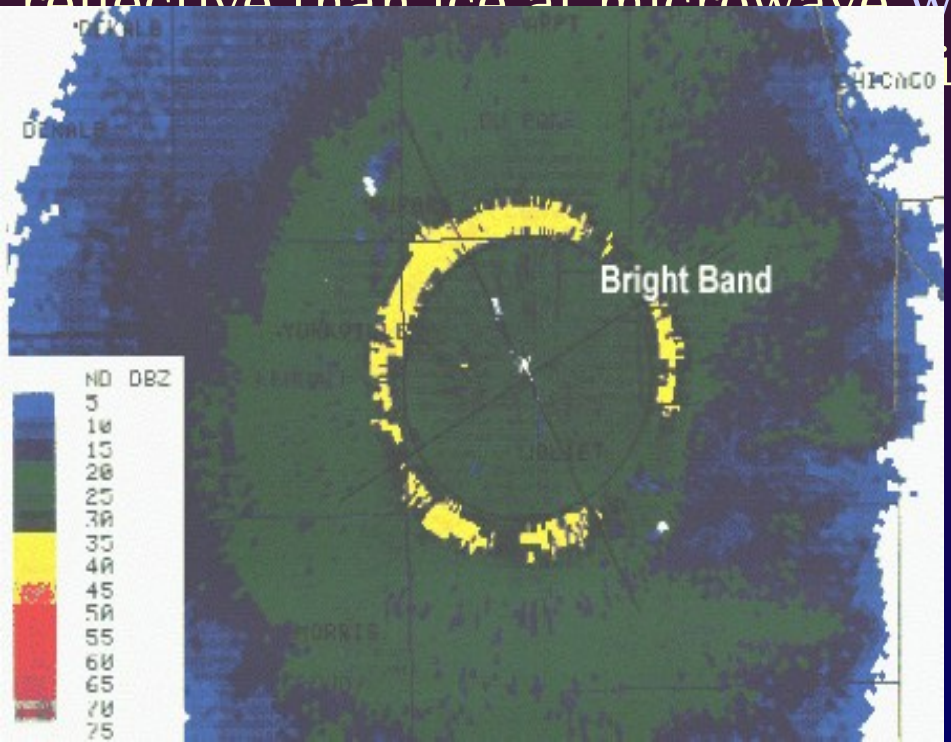
Symbol	Meaning
	Line Of Echoes
SLD	8/10 Or Greater Coverage In A Line
WS999	Severe Thunderstorm Watch
WT999	Tornado Watch
LEWP	Line Echo Wave Pattern
HOOK	Hook Echo

These symbols indicate severe weather

Reflectivity Features

bright band

Precipitation typically forms high in the atmosphere where the temperature is below freezing. As ice crystals form aloft and fall toward the surface, they collect each other to form large snowflakes. As the snowflakes fall, they pass through a level where the temperature rises above freezing. When the snowflakes start to melt, they initially develop a water coating. Water is about 9X more reflective than ice at microwave wavelengths, so these large wet [illegible]ivity.



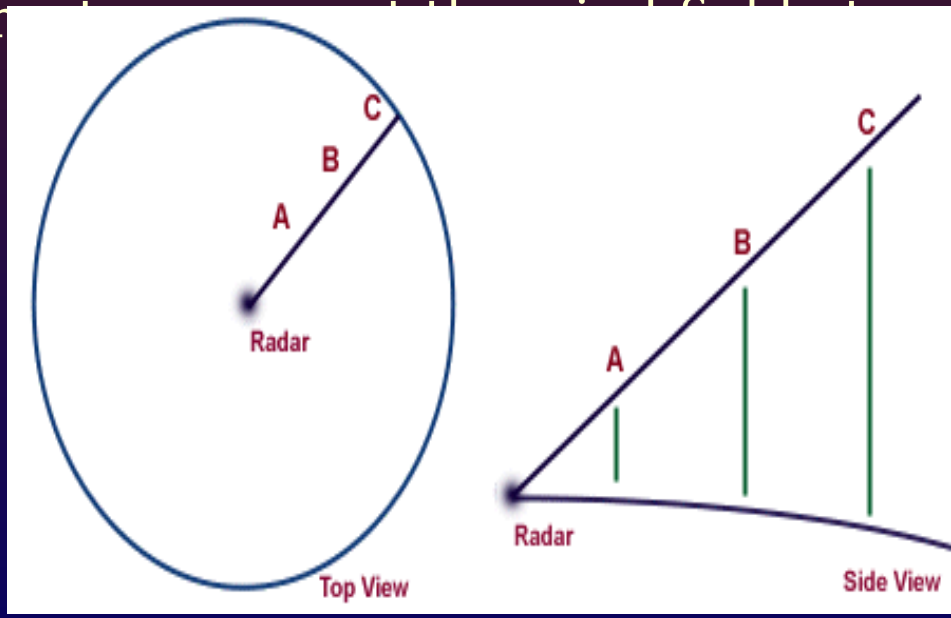
As the flakes continue to fall and melt, they collapse into rain drops. The rain drops are smaller and fall faster, so both the size of the particles and their concentration are reduced, reducing the radar reflectivity. All of these processes lead to the formation of a narrow ring of high reflectivity near the melting

Interpreting Doppler Radar Velocities

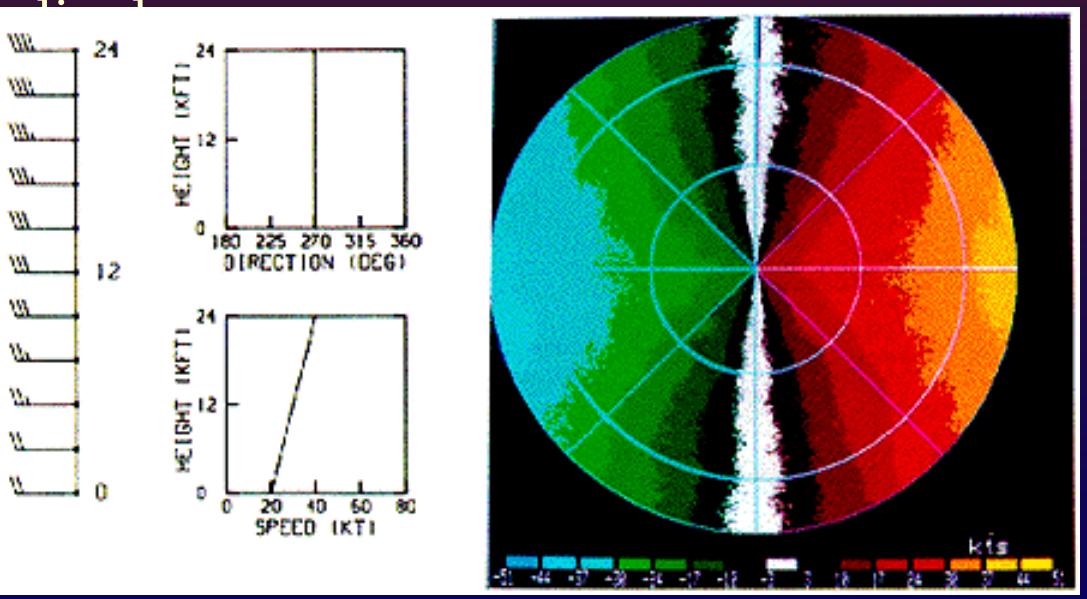
speed shear wind patterns

To understand Doppler radial velocity patterns, one first has to consider the geometry of a radar scan. Normally the radar beam is pointed at an elevation angle greater than zero so that the beam, as it moves away from the radar, moves higher and higher above the surface of the earth. Because of this geometry, radar returns originating from targets near the radar represent the low-level wind field, while returns from distant tar

On a radar PPI display, the distance away from the radar at the center of the display represents both a change in horizontal distance and a change in vertical distance. To determine the wind field at a particular elevation above the radar, one must examine the radial velocities on a ring at a fixed distance from the radar. The exact elevation

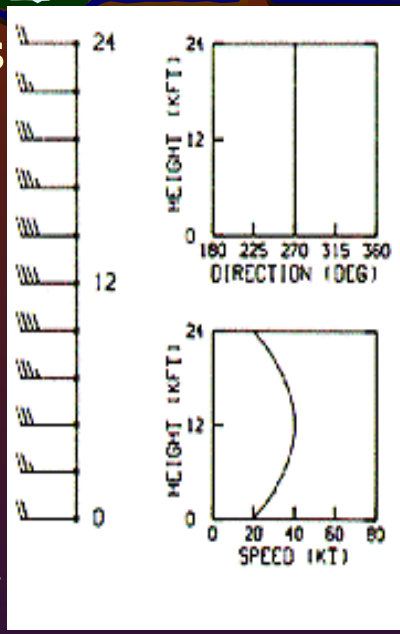


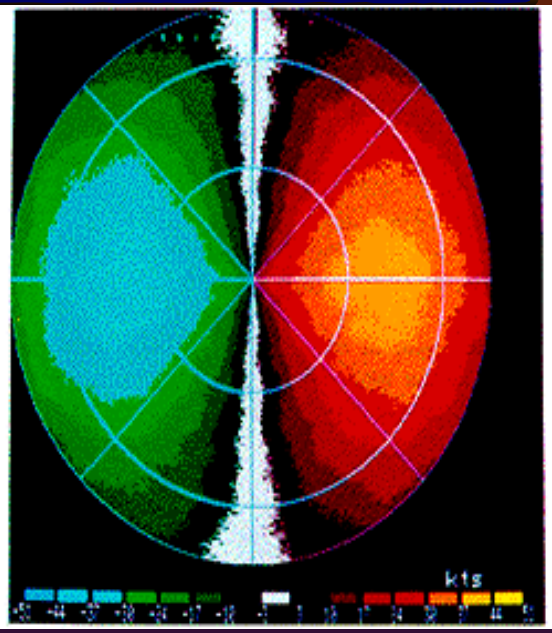
In the examples below, idealized Doppler radial velocity patterns were constructed with a computer assuming simple vertical wind field patterns. These simplified radial velocity patterns can help us understand the more complicated patterns that are associated with storm motions. Doppler velocity patterns (right) correspond to vertical wind profiles (left), where the wind barbs indicate wind speed and direction from the ground up to 24,000 feet. Negative Doppler velocities (blue-green) are toward the radar and positive (yellow-red) are away. The radar location is at the center of the display.

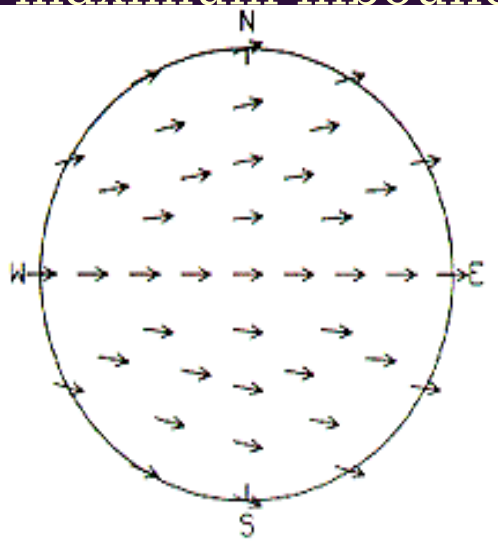


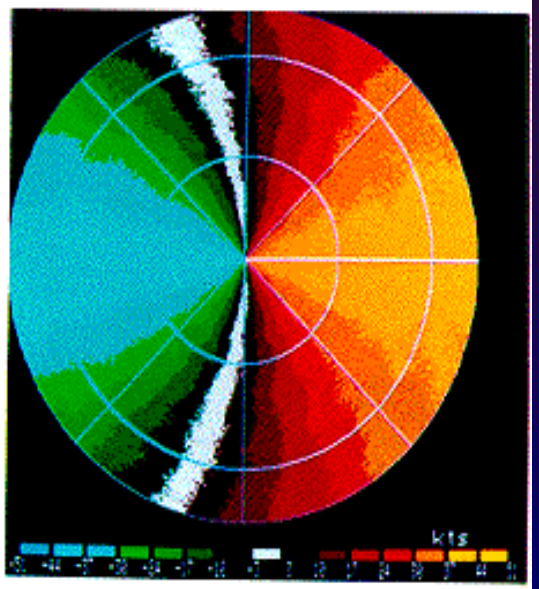
For this first example, wind direction is constant with height, but wind speed increases from 20 knots at the ground to 40 knots at 24,000 feet. Note on the radial velocity field that the maximum inbound velocity is to the west and maximum outbound to the east while to the north and south the radar measures zero radial

In the second example, the winds increase from 20 to 40 knots between zero and 12,000 feet and then decrease again to 20 knots at 24,000 feet. The wind direction again is constant. The radar beam intersects the 12,000 foot level along a ring half-way across the radar display. This is where we see the maximum inbound and outbound



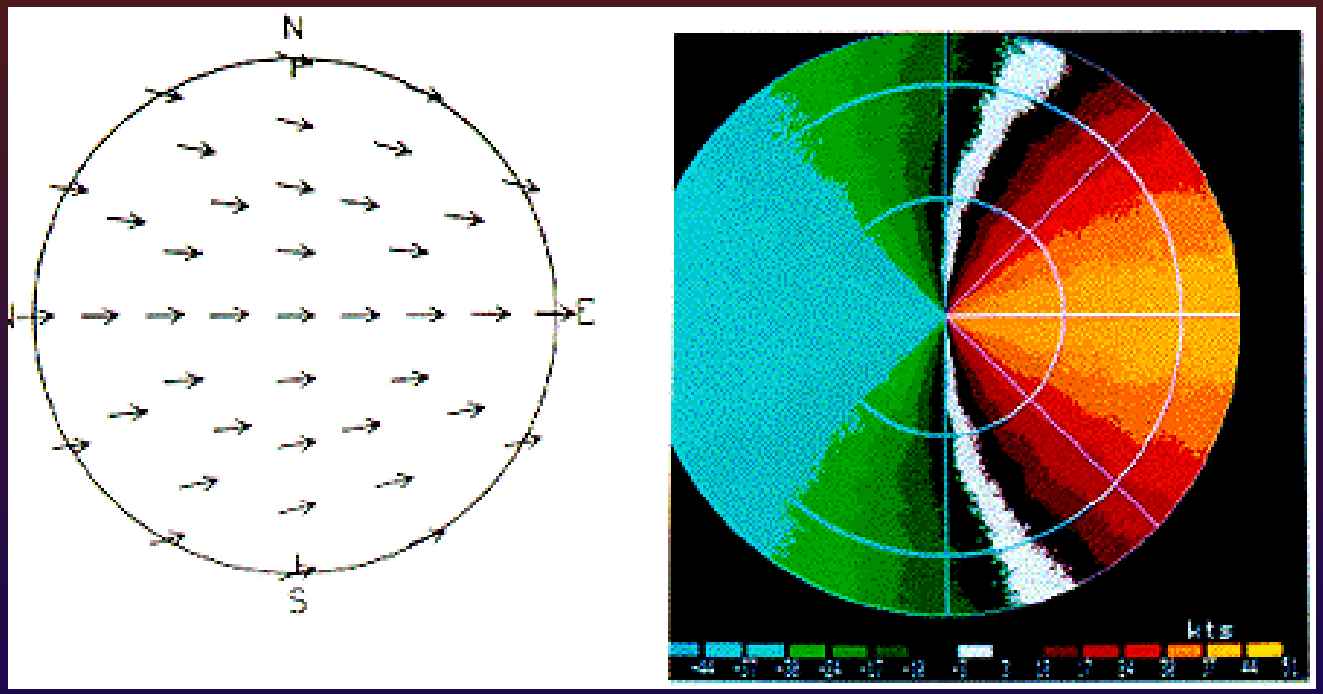






In the third example, we see a wind field which changes direction from north to south but has a constant speed at all heights. The zero radial velocity line now bends so that it is everywhere perpendicular to the wind field. The maximum radial velocities are observed where the radar

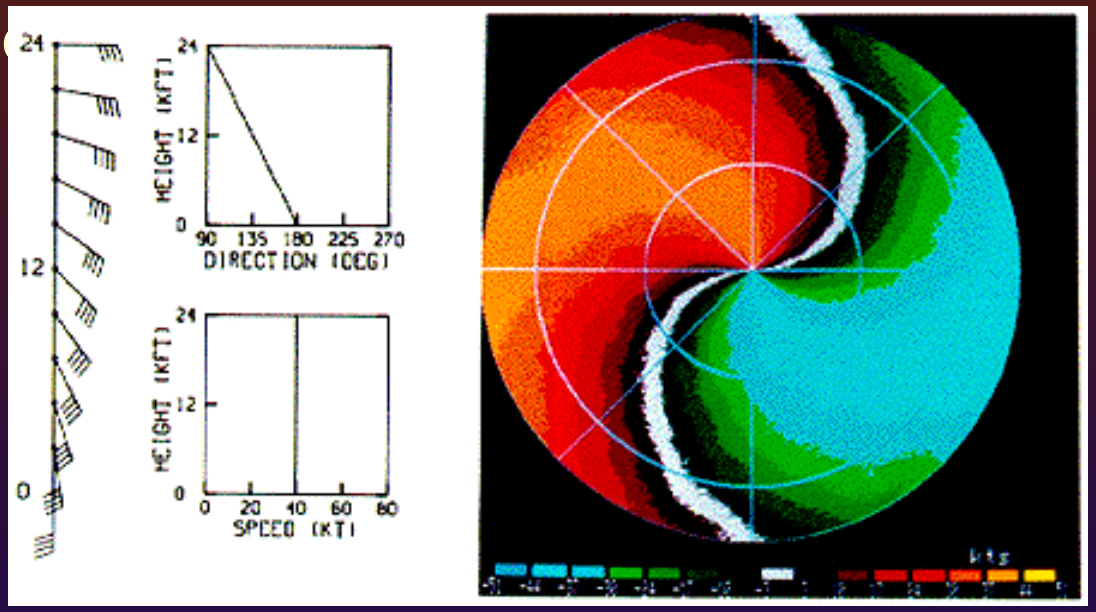
In our fourth example, we see the same effect but in this case, the flow is confluent instead of difluent.



Interpreting Doppler Radar Velocities

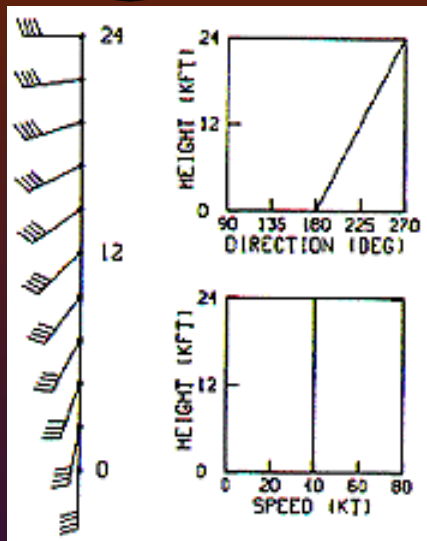
directional shear velocity patterns

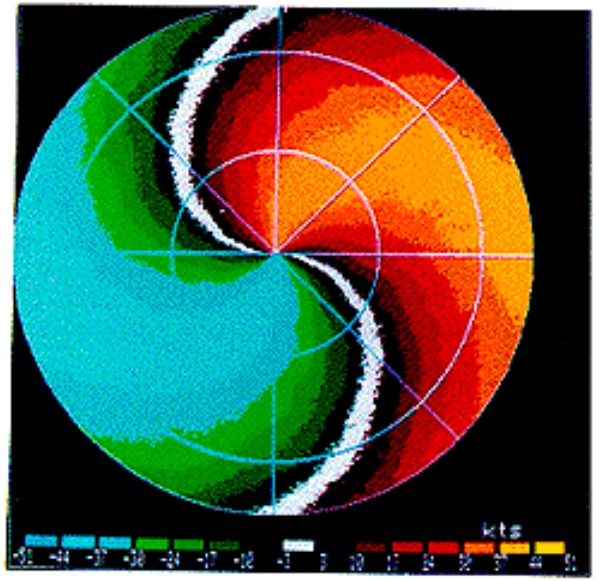
The following examples showcase where the wind direction is

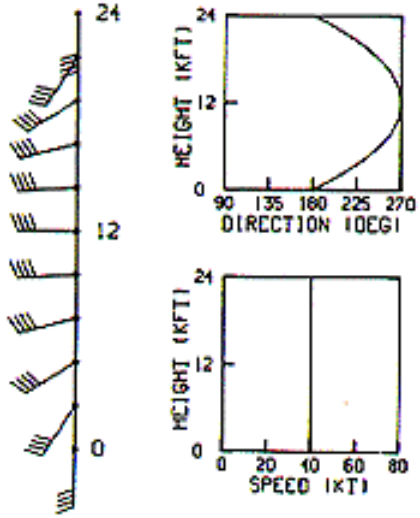


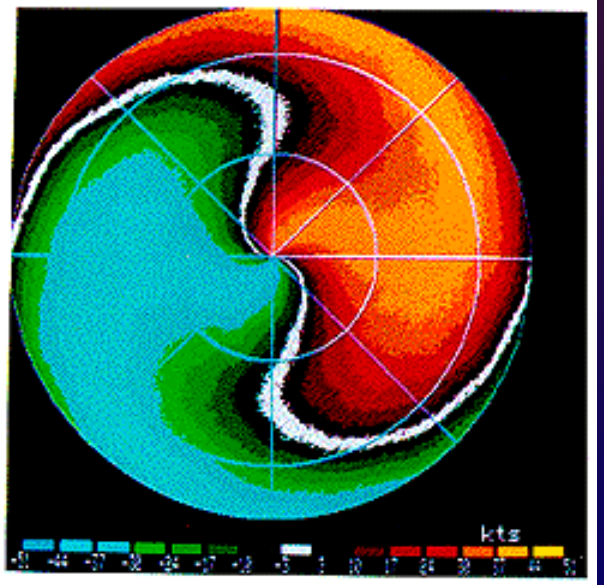
In the first case above, winds back from southerly at the ground to easterly at 24,000 feet. The wind speed does not change. The innermost rings on the radar screen show blue to the south and orange to the north representing a southerly wind. The outermost rings show blue to the east and orange to the west representing easterly winds. Intermediate rings show a progressive change from southerly to easterly as one moves farther from the center of the

In the second example, the interpretation is exactly the opposite. The winds are veering with height and the zero line takes the shape of a normal "S"

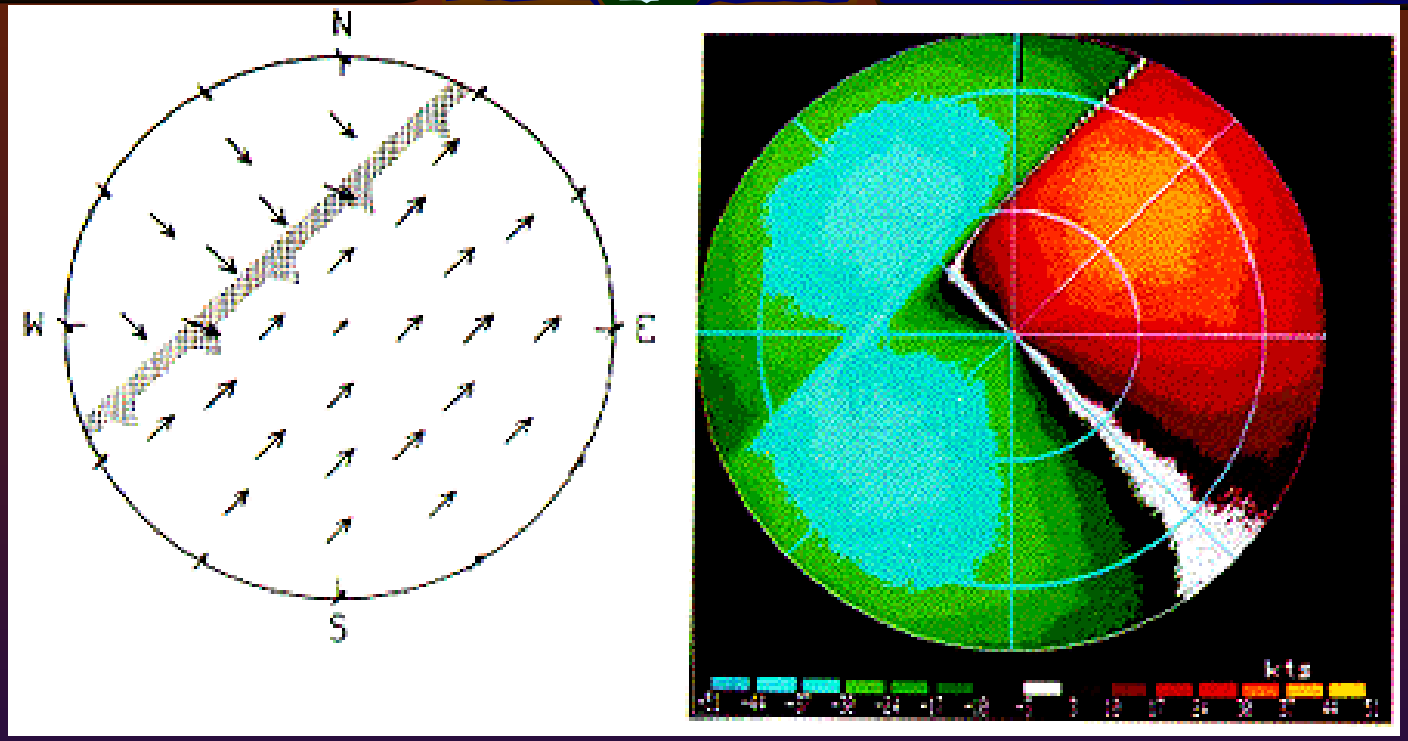








In our third example, winds veer with height to 12,000 feet and then back to 24,000 feet. The inner rings show the characteristic normal "S" pattern while the

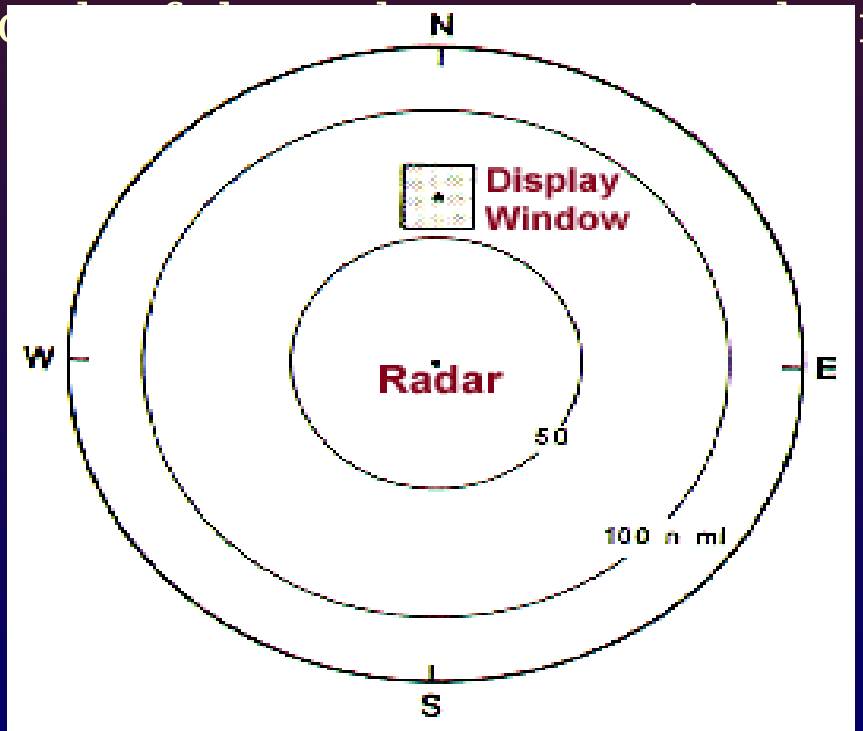


In our fourth example, a cold front is moving toward the radar from the northwest. East of the cold front, winds are from the southwest. The Doppler velocity pattern depicts the southwest winds. Behind the cold front where northwesterly winds are present, all of the winds are inbound toward the radar and appear with blue and green colors. The sharp boundary between the reds and

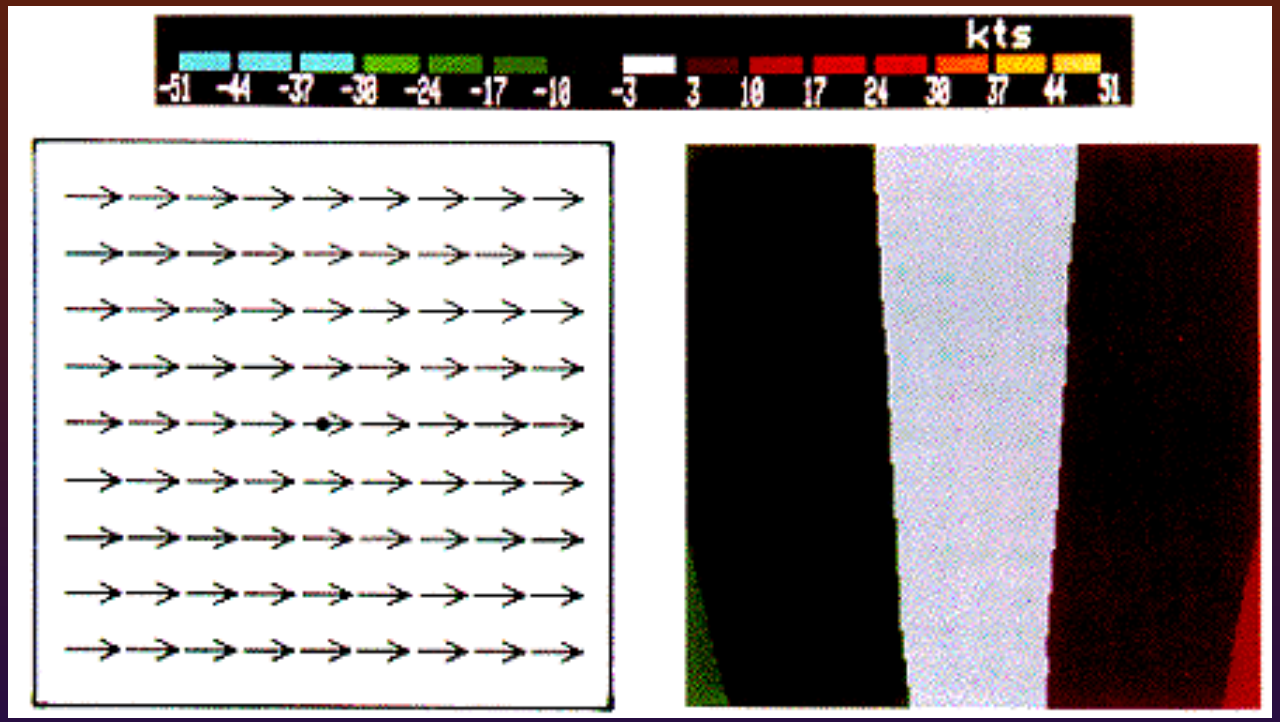
Interpreting Doppler Radar Velocities

straight line winds and rotation

We will now investigate how Doppler velocity patterns vary in a small area of the display where the flow field is uniform, rotating, and flowing outward from a point. These patterns would be similar to what an operator would see with uniform winds, when a mesocyclone associated with a severe thunderstorm was present, or when a downburst was present. We will view a small area located n figure below.

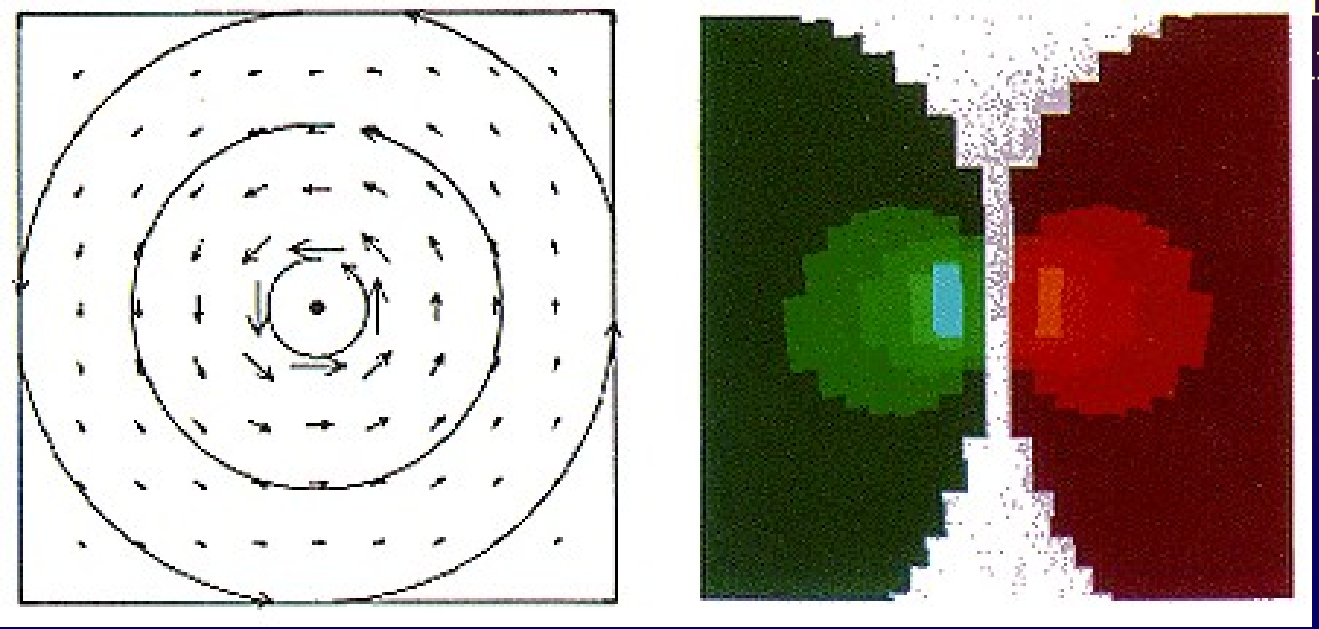


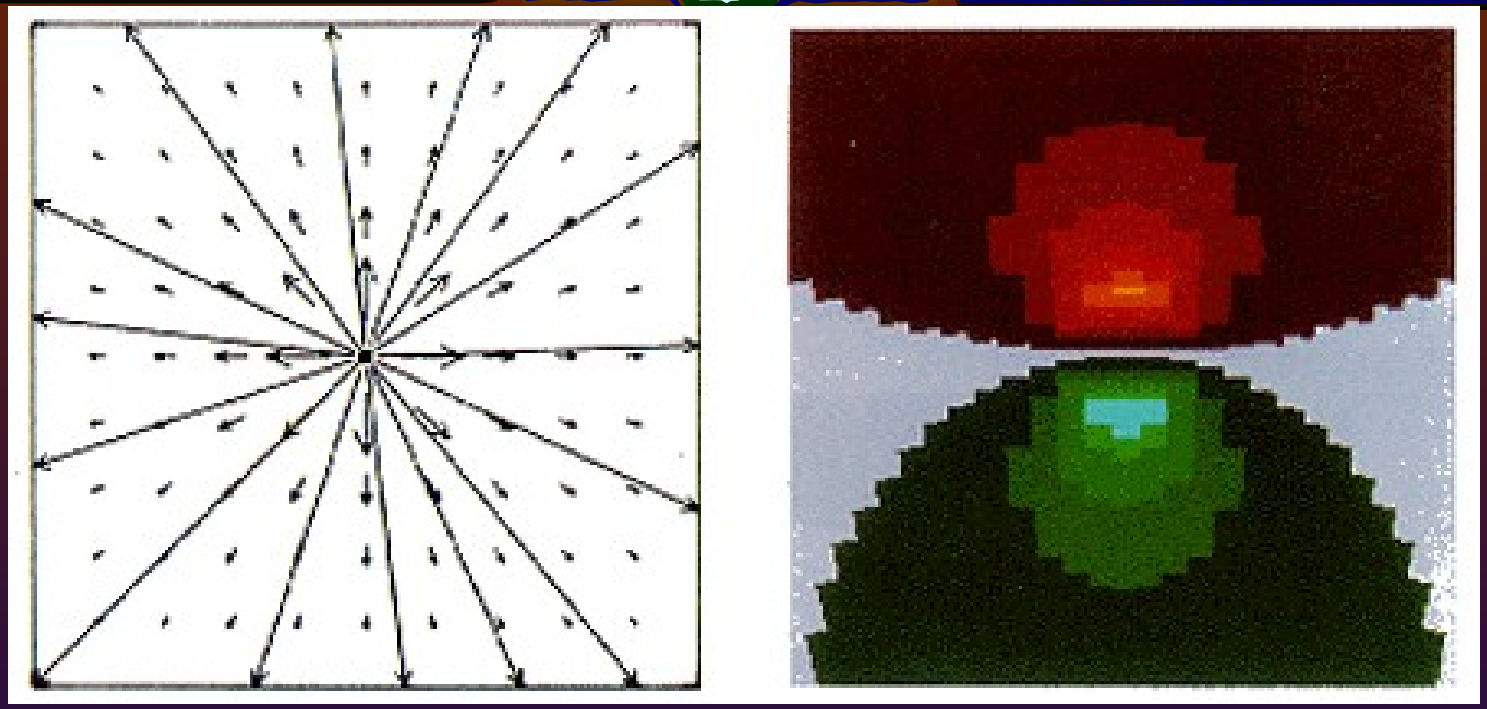
This diagram shows the location and size of the 27 x 27 nautical mile displaying window used for simulated Doppler velocity patterns of convective storm features. The window is 65 nautical miles due north of the radar located at the center of the overall display region.



First, let's look at what a uniform flow field would look like in the small box. The radial velocity pattern on the right is what the radar would see if the wind speed was uniform at 50 knots and the wind was blowing from the west towards the east. Note the zero line goes down the center of the box because the winds are perpendicular to

Next we look at a wind field which is rotating about a point at the center of the box. The wind speeds are 40 knots, 2.5 miles from the circulation center, and decrease outward to zero at the edge of the box. This crudely represents the mesocyclone circulation associated with a severe thunderstorm. The Doppler radial velocity display again shows the zero line down the middle of the box since winds along this line are perpendicular to the radar beam. However, to the left and right of the line, a sharp velocity couplet appears with strong outbound velocities just to the right and strong inbound velocities just to the left. This is the classic signature of rotation with strong inbo xis.



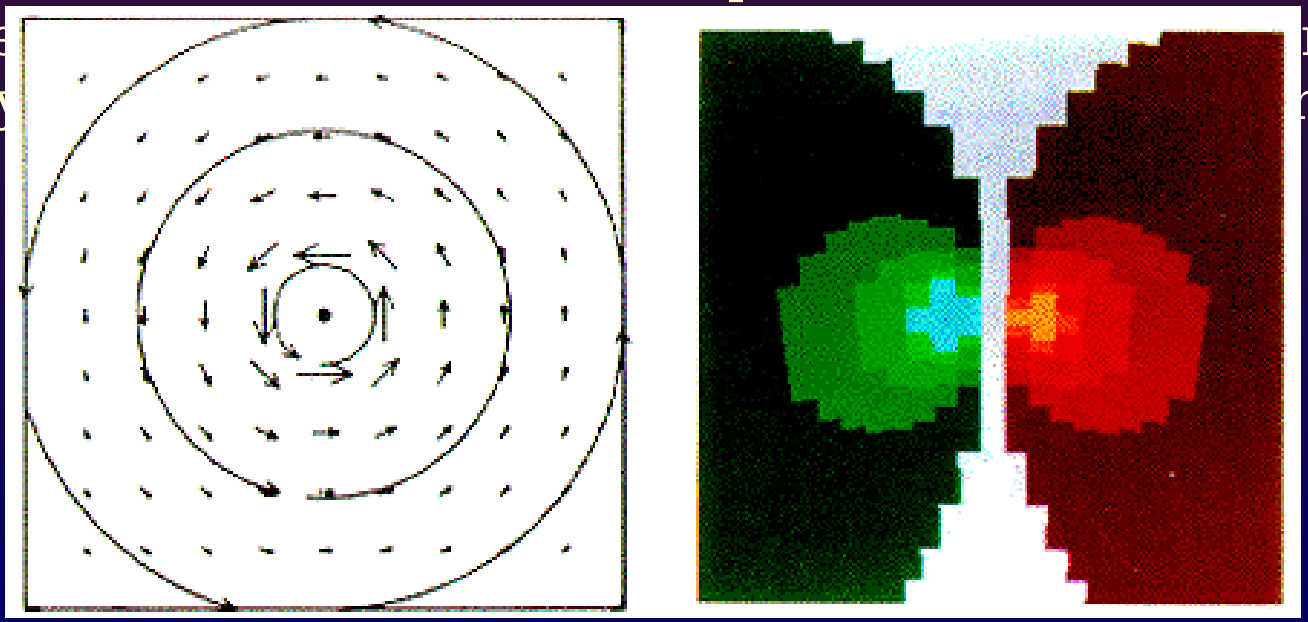


Straight line winds often originate in circulations called downbursts, in which cool descending air strikes the ground at high speed and spreads out in all directions. The leading edge of this cold outflow is called a gust front. The image above shows the Doppler radial velocities associated with an idealized downburst. This Doppler velocity pattern corresponds to an axisymmetric divergent flow where the center of the downburst is in the center of the box 65 nautical miles north of the radar. Note the strong velocity couplet,

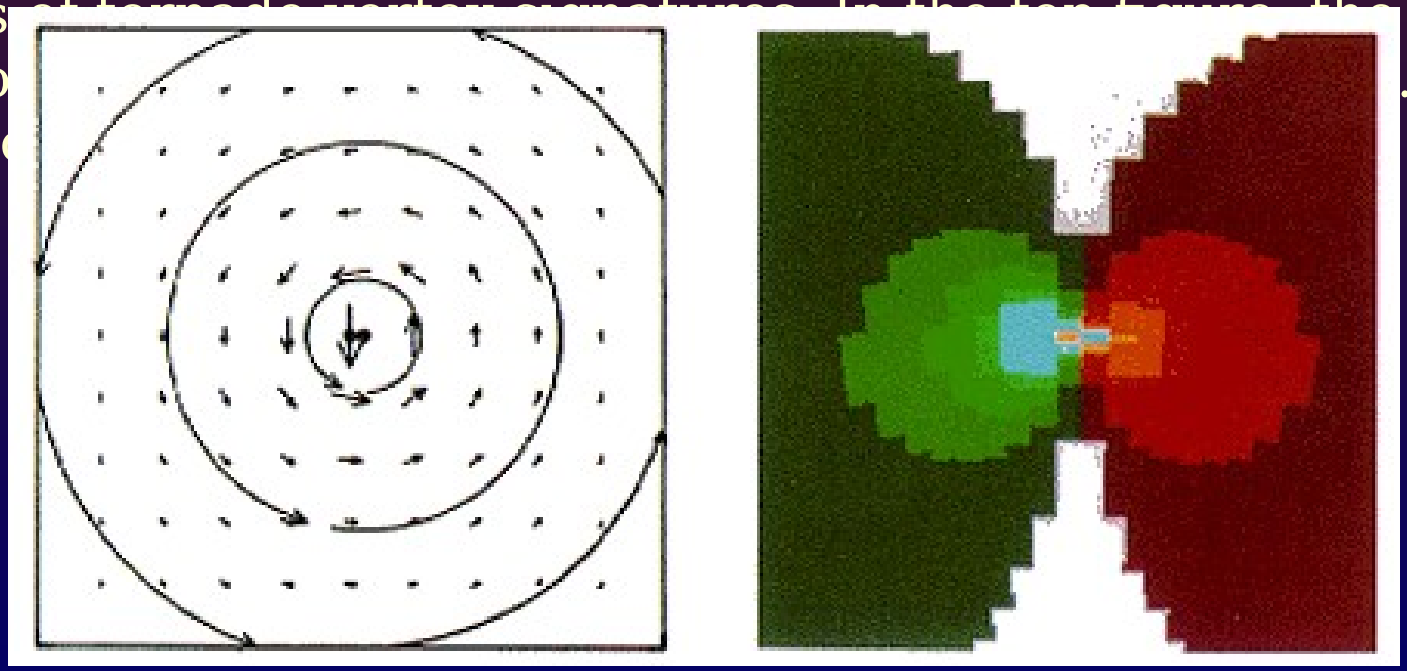
Interpreting Doppler Radar Velocities

velocity patterns associated with tornado vortex signatures

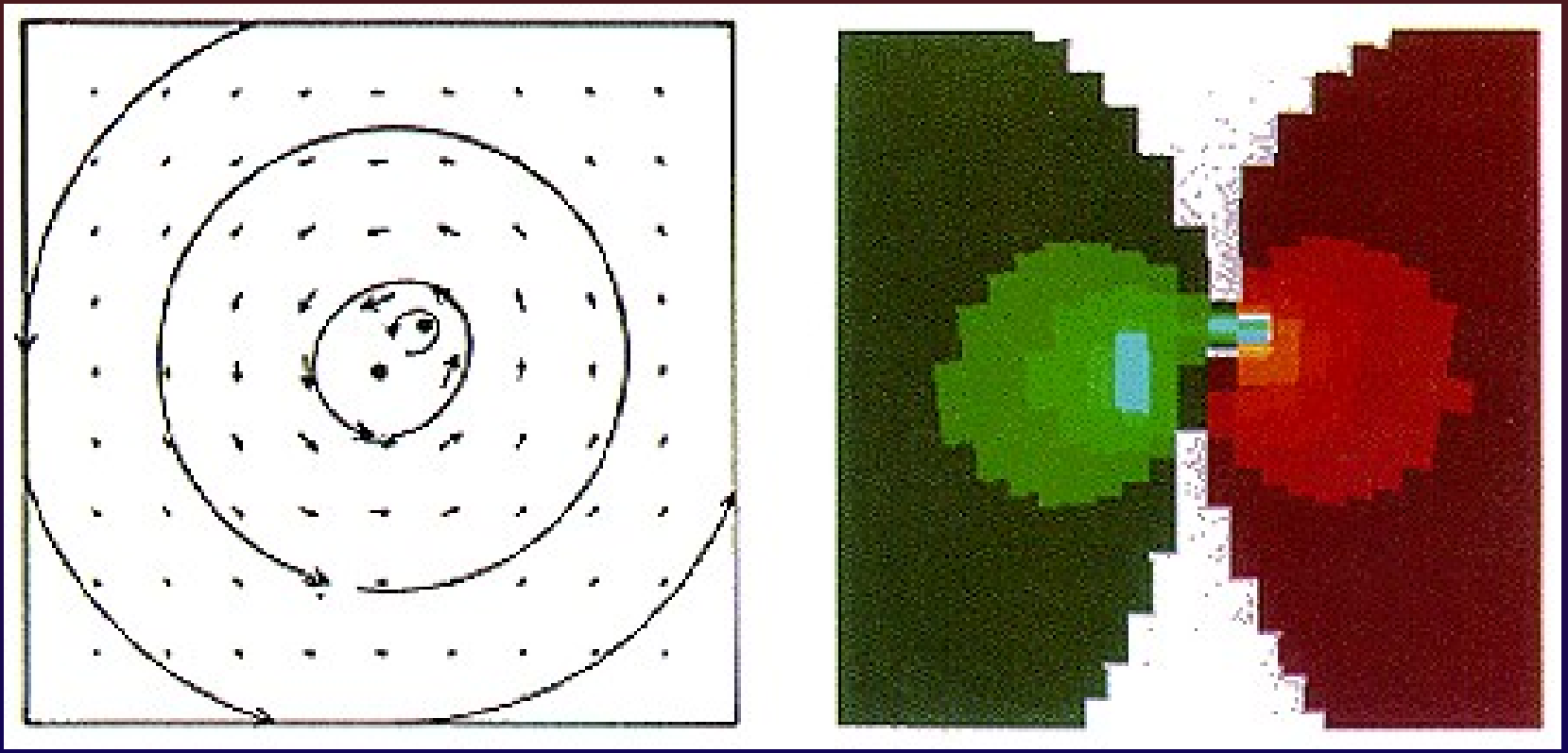
The most important phenomena associated with severe convection are tornadoes. When a tornado is present, it is usually small enough that it fits within one or two beam widths. Depending upon the geometry of the beam, the distance of the tornado from the radar, and the location of the beam relative to the tornado, the strong winds of the tornado will typically occupy one or two pixels. Adjacent pixels will have sharply different velocities, typically with one inbound and one outbound. In the picture below, the mesocyclone
m so that the gray
halves of the display.



Doppler radars have a limited range of radial velocities that they can observe. Velocities beyond that range will be "folded" back into that range such that a strong outbound velocity, just beyond the observable range, will be interpreted as a strong inbound velocity within the observable range. Oftentimes the winds will be so strong in a tornado that the velocities observed by the radar will be folded in the pixel containing the tornado. Tornado Vortex Signatures (TVS) take on different characteristics depending on the geometry and whether or not the velocities are folded. The two figures below show examples of tornado vortex signatures. In the top figure, the circulatio . The radar vel



In the following figure, the tornado vortex signature is located 2.5 miles northeast of the cyclone center.

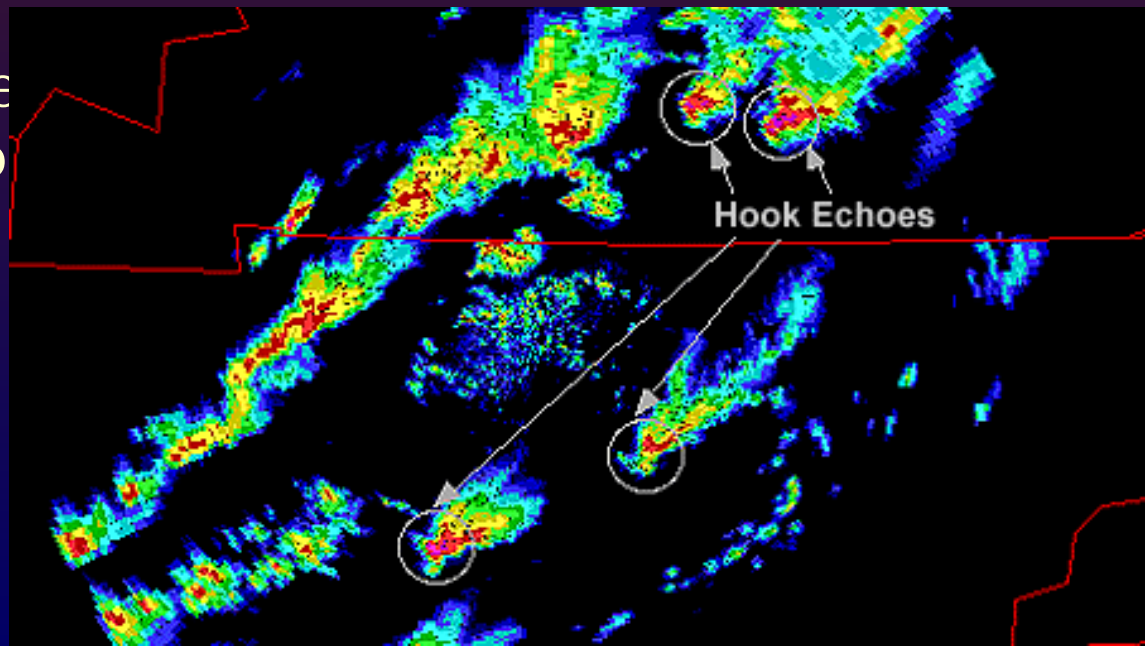


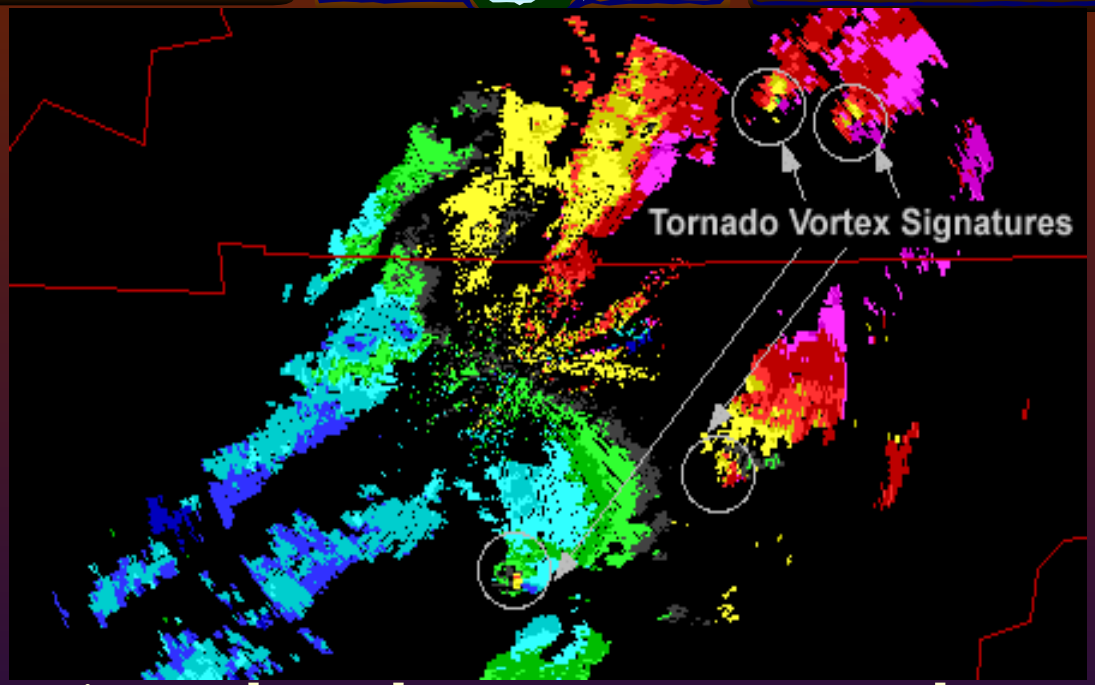
Locating Tornadoes

hook echoes and velocity couplets

Tornadoes are often located at the center of a hook-shaped echo on the southwest side of thunderstorms. The hook is best observed in the reflectivity field. This image shows a reflectivity field containing several hook echoes associated with thunderstorms that occurred in Tennessee and Kentucky on May 18, 1995.

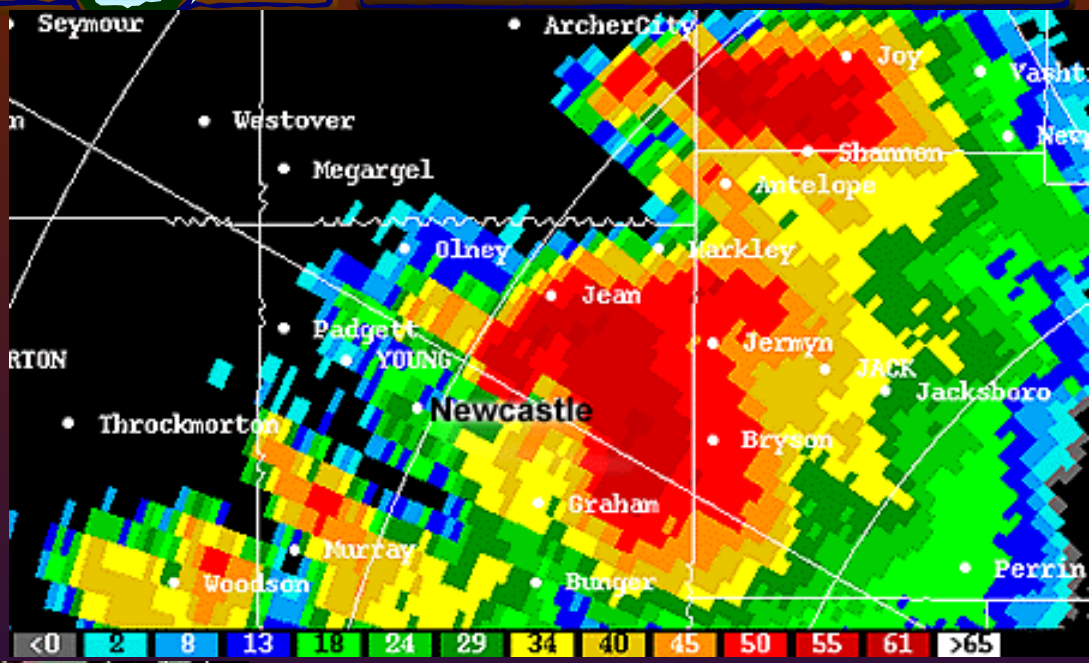
Another way to determine if a storm is tornadic is to examine the radial velocity field. A mesocyclone, the small rotating circulation with its center beneath the updraft of a supercell thunderstorm, is

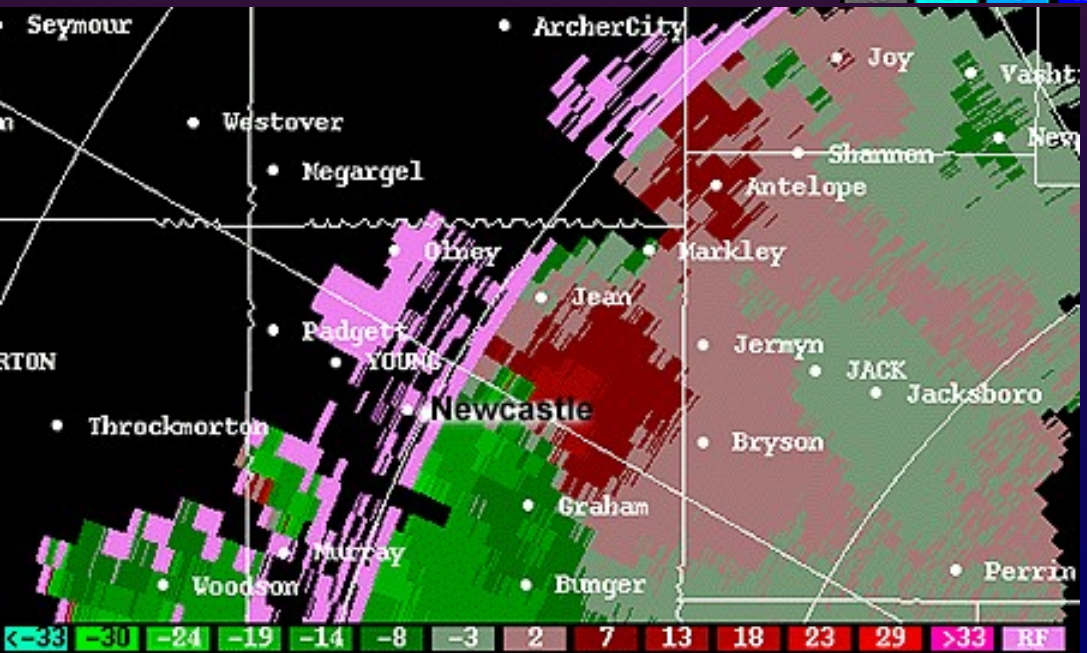




The couplet is oriented so that a concentrated area of radial winds moving away from the radar appears on one side of the beam axis, while a concentrated area of radial winds moving toward the radar appears on the opposite side of the beam axis. When the central pixels near the beam axis show exceptionally strong winds, this signature is called a tornado vortex signature (TVS). This image shows the TVS in the velocity field from the same Tennessee and Kentucky storms. Negative values (blue-green) denote movement toward

Here is the reflectivity field from a storm which produced a tornado in Texas on May 29, 1995. The hook echo in the reflectivity field is located near Newcastle.





Here is the velocity couplet associated with the Newcastle hook echo (red and green pixels adjacent to each other)

Hurricanes on Radar

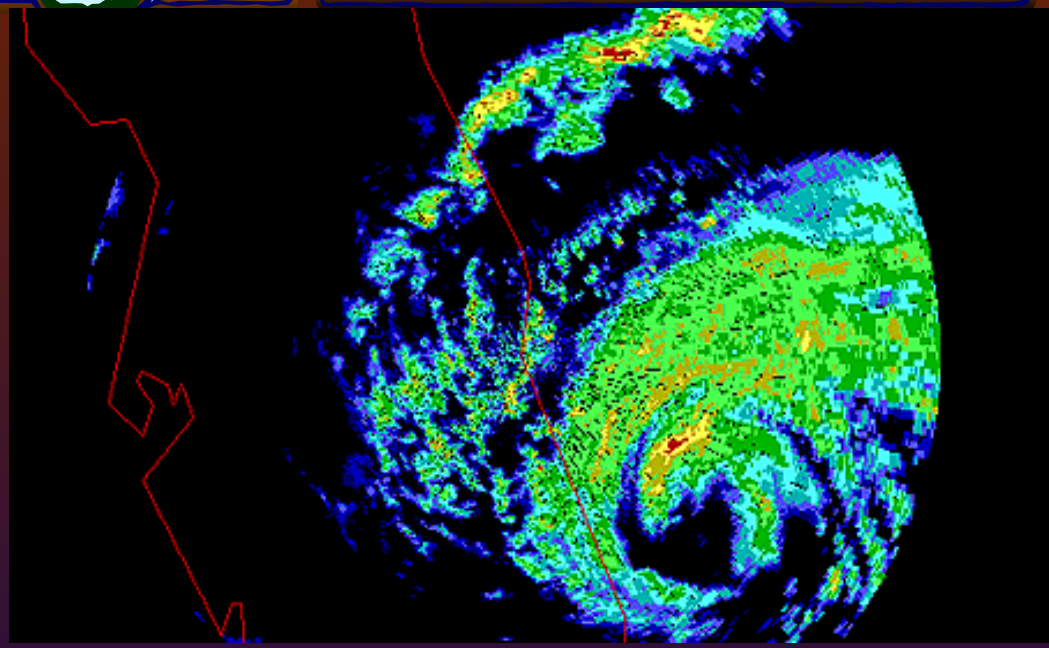
circular areas of moderate to high reflectivity

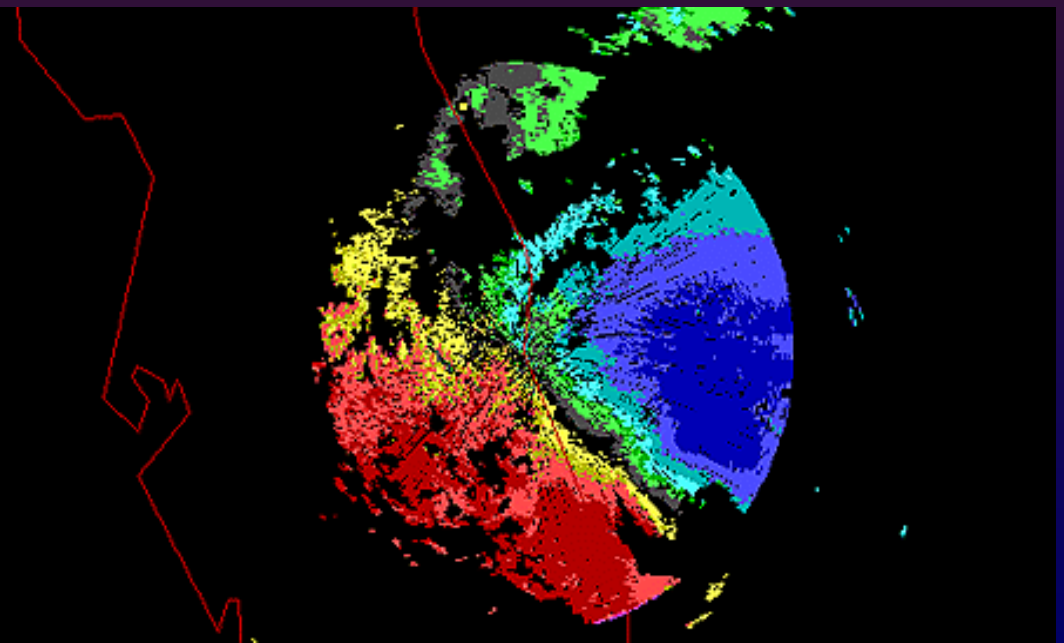
Hurricanes show up clearly on radar as circular areas of moderate to high reflectivity, often surrounding a low reflectivity center.

This image shows the reflectivity field from the eye wall of Hurricane Andrew. The symmetry shown in this image indicates that Andrew was a very well developed hurricane. The ring of orange are the high reflectivities associated with the convection found in the

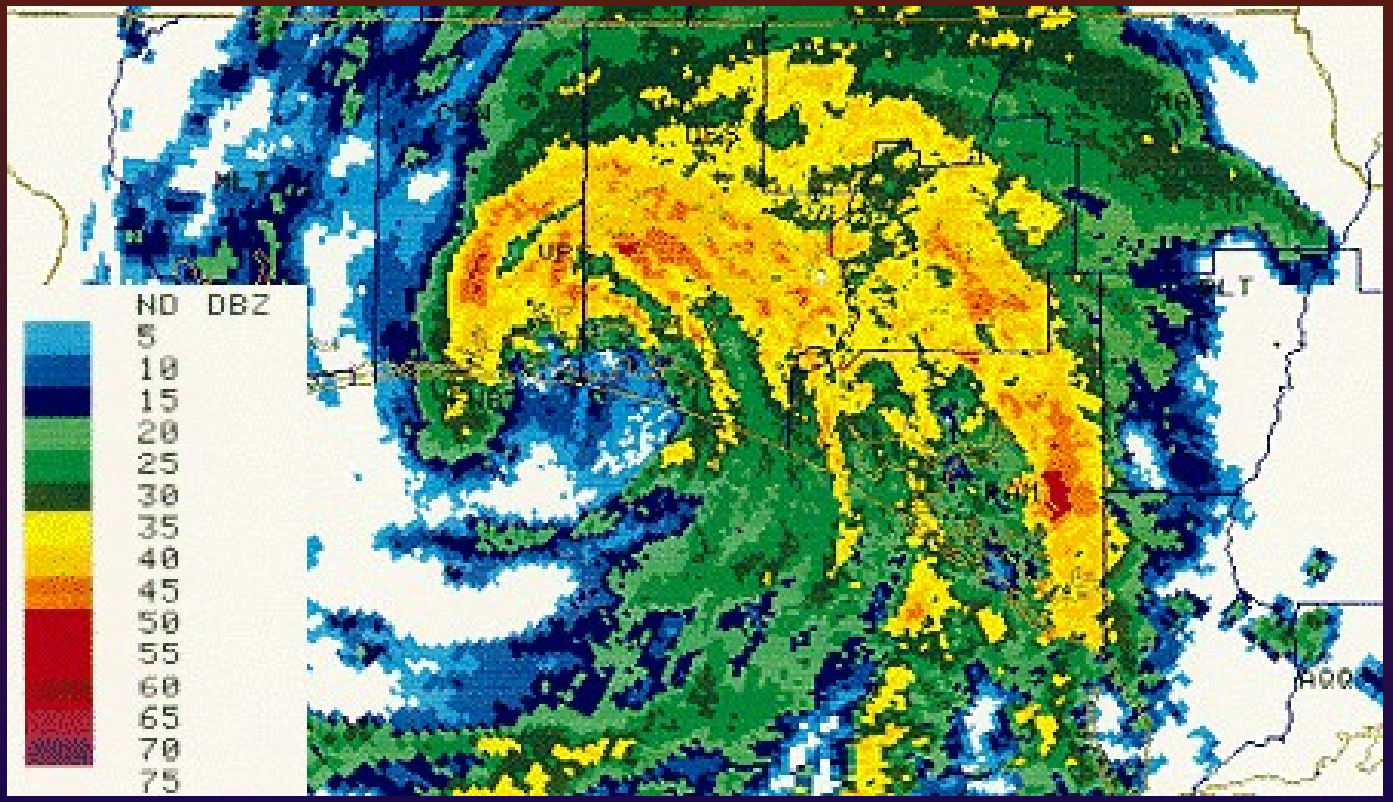


This image shows the reflectivity field from a scan of Hurricane Erin on August 2, 1995. The lack of symmetry indicates that Erin was a rather weak hurricane, especially compared to Andrew.





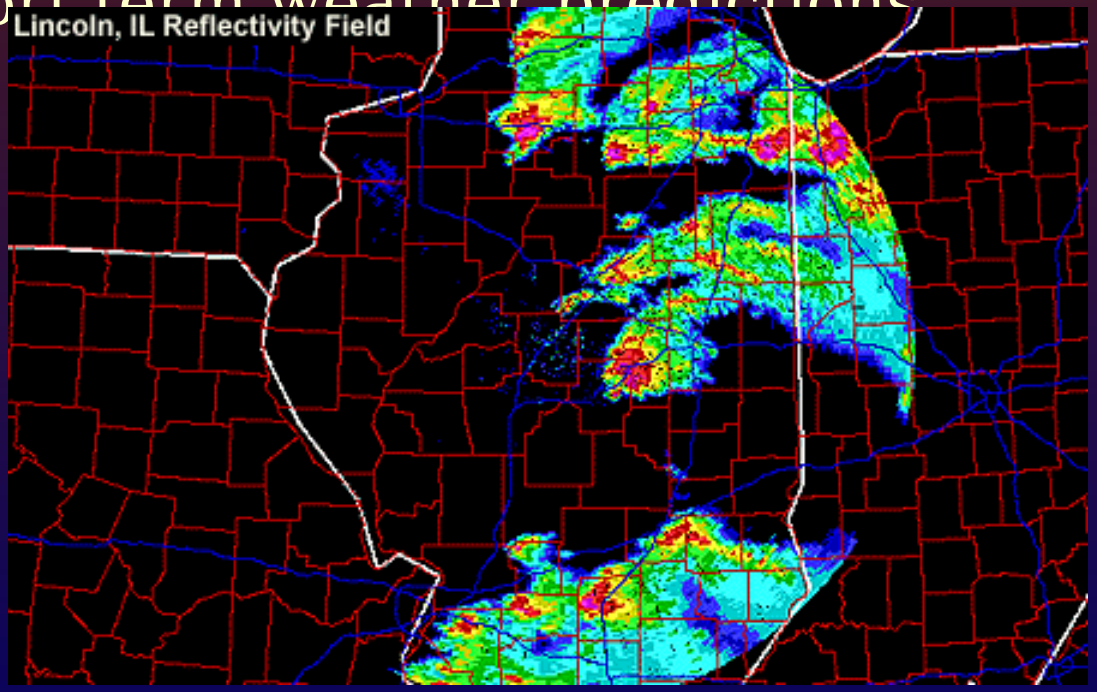
The velocity field of Hurricane Erin reveals the strong counterclockwise rotation responsible for the inward flow on the storm's north side and the outward flow on the south side. Negative values (blue-green) denote movement toward the radar and positive values



This image shows the reflectivity field from a scan of hurricane Roxanne on October 19, 1994. High reflectivities north and east of the eye are associated

advantages of radar data

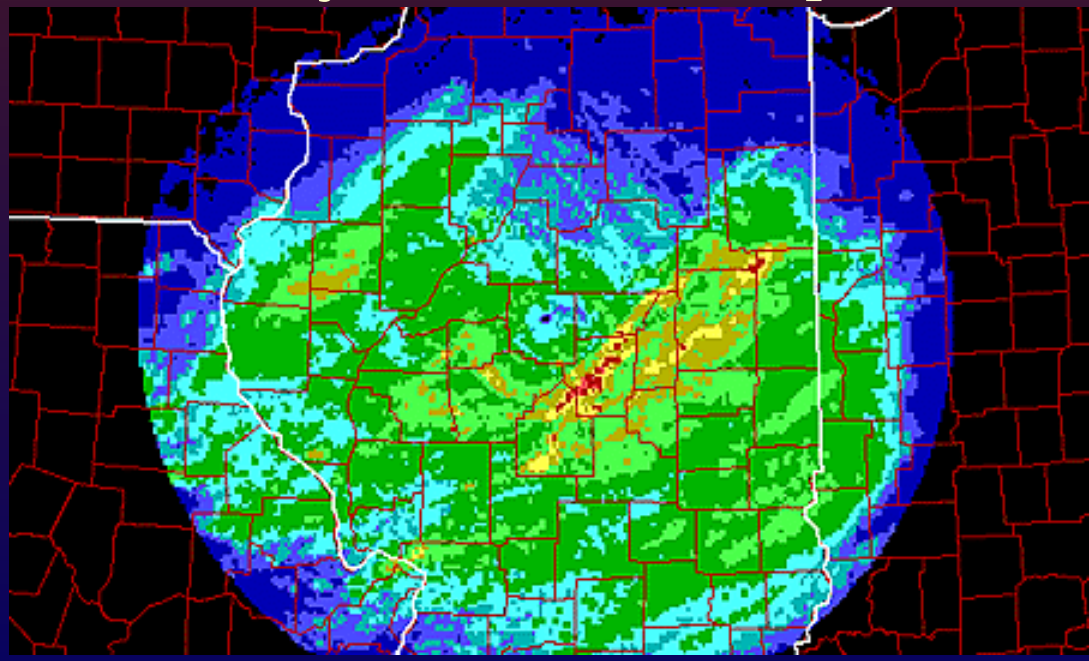
Using radar data, a forecaster can determine the nature of any existing weather systems and follow their movement and evolution. This is a valuable tool for making short term weather predictions.



Flash Floods

radar data is used to issue special weather statements

This image shows a map of radar-estimated precipitation totals for a 12 hour period. Since the radar reflectivity is closely related to the precipitation rate, the total amount of precipitation falling on a region over a fixed period of time can be determined by analyzing reflectivity field over that period.



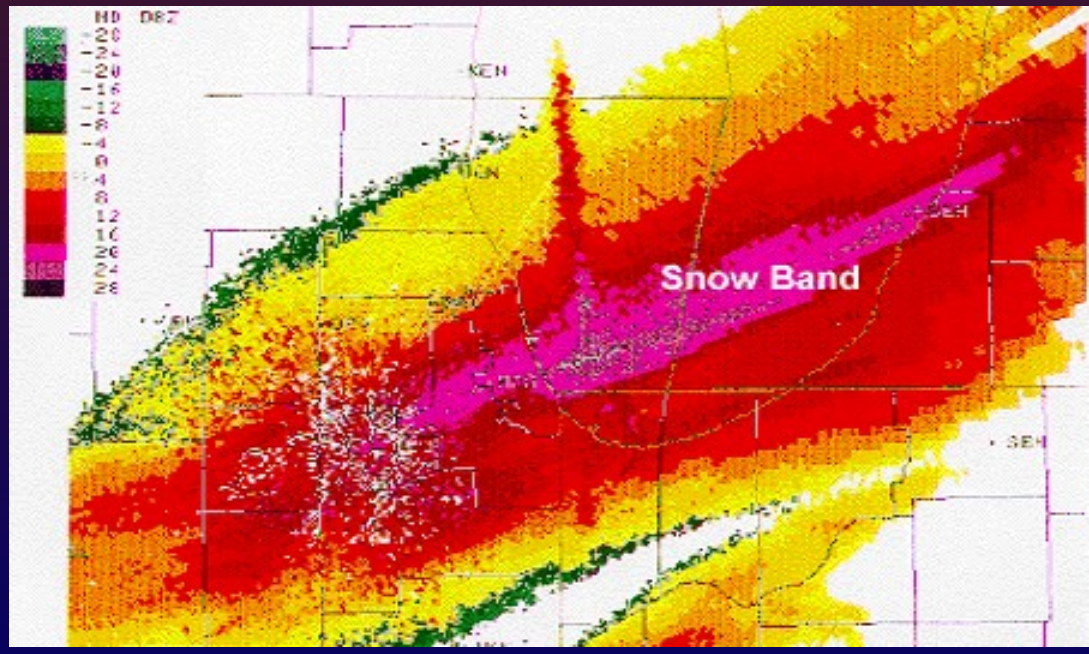
The heaviest amounts are indicated in yellow and red. Flash flood warnings would be issued for the stream and river basins which drain these areas.

Snow Storms

radar data is used to identify bands of heavy snow

This image shows the different scales on which snow can occur. The large snow band extending across the figure is associated with a large storm system moving across the country.

Superimposed on the large system, is a smaller scale snow band located off the west shoreline of Lake Michigan. Each of these bands individually produced heavy snow and where they intersected near



Hai
l

indicated by regions of very high reflectivity

This image shows some severe thunderstorm cells in western Illinois and eastern Missouri on April 19, 1996. The small regions of high reflectivity (shades of purple and gray) located near the edges of these storms are likely to be regions where large hail is falling. Typically, radar reflectivities associated with hail have v

